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STUDIES IN ELECTRO-PHYSIOLOGY

STUDIES IN ELECTRO-PHYSIOLOGY

(Animal and Vegetable)

By
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WITH THIRTY-ONE ORIGINAL DRAWINGS
IN COLOUR, ILLUSTRATING THE ELECTRICAL
STRUCTURE OF FRUITS AND VEGETABLES

By
GLADYS T. BAINES

And numerous other Illustrations

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*

1918

THIS WORK IS DEDICATED
TO
THE MEDICAL PROFESSION
IN THE HOPE
THAT IT MAY INTEREST AND INSTRUCT, AND
PAVE THE WAY
TO
FRESH CLINICAL ADVANCE
ALONG
THE LINES HEREIN
SUGGESTED

ERRATA

Page 84 ; line 5. *For "Separates it" read "Separates the foliage."*

Page 57 ; line 1. *For "2,000" and "40" read "200" and "400."*

Page 95 ; line 2. *For "15 and 5" read "5 and 15."*

Page 98 ; line 5. *For "points are" read "points is."*

Page 119 ; fig. 81. *For "controsphere" read "centrosphere."*

Page 148 ; line 29. *For "Gynostemium" read "Gymnostemium."*

Page 169 ; line 20. *For " SO_4 " read " SO_8 ."*

Page 172. Inverted commas should commence on line 80, after "subject."

Page 178 ; line 20. *For "to the lower thigh-bone" read "to the leg bone." Line 28 : For "upper and lower thigh-bones" read "upper and lower bones."*

PREFACE

I HAVE been encouraged by several medical friends, and particularly by my fellow students, Drs. White Robertson and E. W. Martin, to make an excursion into the realm of Electro-physiology ; a subject which I had previously been reluctant to take up in the declining years of my life owing to the controversy which any new view of the operating forces of the body would be sure to provoke. But the matter at issue is too important for personal considerations to outweigh a possible advance in knowledge.

For more than half a century theories which were without any real scientific basis have barred the way to progress, and the rebutting evidence hitherto at command was in itself insufficient to compel adequate attention, although it was, upon careful examination, enough to refute the theories in question.

In a former work* of an unambitious character I considered the nature and distribution of nerve force from a new standpoint, and it followed that if I had discovered a fundamental principle my research work must harmonise with established laws and enable me, in accordance with those laws, to explain not only the nature and source of the force but to show how by its means the various functions of the body were called into operation.

The two theories of the nature of the nerve impulse, the physiological and the physical, are, in the present state of our acquaintance with the subject, equally unsatisfactory, but it has always been clear to my mind that upon investigation the body structure should make it manifest whether it was primarily designed for electrical or chemical functions ; or rather, whether it was evident from its

* *Electro-Pathology and Therapeutics.*

structure that electrical action was precedent to chemical change. If not, if, on the contrary, the body consisted of a congeries of chemical laboratories, with only an occasional suggestion of an electrical circuit, then I was self-deceived.

To this day we electricians do not *know* if in a galvanic cell electrical begets chemical action or *vice versa*. But in the form and appearance of a galvanic cell there is nothing to guide us to definite opinion, much less to afford conclusive proof. What is electricity? There are the one-fluid and two-fluid theories. Dr. Le Bon has found that the particles emitted from an electrified point are identical with those of radium; carbon when suitably treated will give off a form of energy resembling electricity but which can be shown to be some other element—if electricity is an element. We talk glibly of ions and electrons—although we know very little about them—and are constantly advancing new theories as if they were laws, and endeavouring, and failing, to make results agree with them. There is only one law, and upon that law all creation is founded; one law for the living and a modification of it for the dead. There are, of course, differences of structure and perfection of structure, but the same law, as I hope to show in these pages, governs without exception everything that lives upon this earth, animal and vegetable alike.

A. E. BAINES.

London, 1918.

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INTRODUCTORY

RECEIVING a first education in telegraphy, in the Post Office under my uncle, F. E. Baines, C.B., First Surveyor-General of Telegraphs, and Mr. (afterwards Sir) Wm. Preece, I joined the service of the Eastern Telegraph Company in the early seventies, and as the story of how I became interested in electro-physiological research may not be without interest, some personal details are perhaps admissible.

Much about the time of which I am writing I was chief assistant electrician—under my old friend Professor Andrew Jamieson—of the cable-ship *The John Pender*, belonging to the Eastern Telegraph Company and then engaged in repair work in the Red Sea and Indian Ocean.

An unfortunate accident to my chief left me for a time in charge, and I had as one of my juniors for a brief period A. E. Kennelly, now Professor of Electrical Engineering at Harvard University.

Submarine cables, however, are not always breaking down, and during an idle interval in the year, so far as my recollection serves me, 1880, my employers lent me to Mr. Finlay, of the Cape Observatory, to assist him in correcting longitudinal data by means of time signals transmitted over the company's cables between Aden and Durban.

It was necessary to receive signals upon a reflecting

mirror instrument while listening to the loud ticking of the seconds of a clock specially made for astronomical work. The signal had to be sent from one end and recorded at the other at the exact tick, and Mr. Finlay showed me the importance of determining my personal coefficient of error in reading in order that allowance might be made for it.

Some time afterwards, while engaged in cable-testing at Delagoa Bay, I noticed a deflection upon the scale of the Astatic reflecting galvanometer for which I could not account, and upon investigation found the disturbing influence to proceed from my own body. This led to a series of experiments which convinced me that a force resembling electricity, if not identical with it, was constantly generated in the body, and that its tension was dependent upon the state of health of the subject.

Some few years later I was invalided home, and at the instance of Sir James Anderson and Sir John Pender—to whom the journal then belonged—was associated in the editorship of *The Electrician*, and also became editor of *The Electrical Engineer*. In the latter paper, in May, 1885, I published an article entitled “The Human Body as a Disturbing Element in Electrical Testing,” from which the following quotation may be made:—

“I am of opinion that in every case where use is made of an unshunted galvanometer of great sensibility the operator should be careful to connect himself during the test with an earth plate, instead of, as is usual, standing upon some insulating substance. This conclusion was forced upon me years ago. I was, in the ordinary course of business, comparing a 10-microfarad condenser with one of 1-micro capacity by Sir William Thomson's ” (afterwards

Lord Kelvin) " method, employing a very sensitive Astatic galvanometer and two platinum-silver resistances, arranged so that a difference of one ohm resistance gave me a difference of 0.001 microfarad capacity. The insulation of the battery and other apparatus was absolutely perfect; I used a current due to very low electromotive force, in order to avoid heating, and took all the precautions which are laid down by others and which our own experience suggests. The 10-micro condenser varied in the most inexplicable manner between 8.929 and 9.981 micros. In all there might have been a hundred readings taken, each time, or almost each time, with a different result, with a discrepancy of about 0.001 micro, and it was not until I observed a slight galvanometric deflection while the battery circuit was open that the probable cause suggested itself to me. During the course of some experiments I afterwards made under different conditions to verify the idea then formed, I stood as closely as possible to the galvanometer circuit, and upon being charged with 20 volts produced a slight *inverse* deflection upon the galvanometer; when the circuit was opened a slight *direct* deflection was noticeable. After having connected myself with an earth of low resistance the phenomenon ceased to manifest itself and I succeeded in getting a balance. '

My association with Mr. Finlay, short as it was, was fortunate. Had it not been for that association I should, in all probability, have dismissed the vagaries of the galvanometer as being due to leakage, and, so far as I am concerned, the experiments might never have been made.

Hundreds of other electricians have observed the same phenomena during the last thirty or more years, but have not bothered themselves to do more than attend to the

insulation of their connections. Temperament may have befriended me, but the germ of carefulness was implanted by Mr. Finlay, and I am grateful to him for it.

The article from which I have quoted attracted the notice of Dr. Stone of St. Thomas's, a correspondence resulted, and, eventually, I collaborated, unofficially, with him in the preparation of his Lumleian lecture of the year, the subject being, "The Human Body Considered as an Electrolyte."

At that time I am afraid we, neither of us, knew very much about it, but although working in different sections of the field of scientific investigation, we had both arrived at one conclusion, viz., that local pyrexia interfered with local insulation resistance.

The importance of this discovery can scarcely be over-estimated, but we did not realise it; he, not before his death, which occurred not long after, I, not for many years, because other occupations and duties intervened and research work had to be relegated for the nonce to the background.

It was some time about the year 1900 that I fitted up a laboratory and seriously took up my task anew. And then a curious thing happened. We had a juvenile party, and some of the young people, inspired, perhaps, by a magazine article or fairy-tale, asked me if apples were electrical, if one could eat things which would make one luminous, and so forth. I replied, "Come and see." We went into the testing-room, and having procured some apples and oranges and lemons, I connected two steel darning-needles by two lengths of flexible wire to the terminals of the galvanometer and, of course, obtained deflections. These experiments were regarded by me, at

the time, as "parlour tricks," and in making them I had no object other than the amusement of the youngsters. But when upon reversing an apple I obtained a reversal of sign my interest was keenly aroused and a series of experiments was initiated which are described in Part I, and which, so far, touch little more than the fringe of the subject.

From that time I went on working patiently between intervals of strenuous commercial and professional life, saying nothing, publishing nothing, but collecting data upon which to found a considered opinion—and this present volume is the result.

A. E. B.

Part I

ELECTRICAL STRUCTURE AND FUNCTION IN PLANT LIFE

STUDIES IN ELECTRO-PHYSIOLOGY

CHAPTER I

GENERAL

It has long been known that the application of electricity to the soil is sometimes beneficial to plant life, and some remarkable results in the direction of increasing the quantity and quality of crops have been in that way obtained. But hitherto no adequate attempt seems to have been made to ascertain if Nature has endowed the vegetable world with any system by means of which currents of electricity can be utilised, assimilated, or stored.

The experiments, therefore, conducted during the past thirty or more years have not been altogether conclusive, and no really satisfactory evidence has yet been obtained beyond the fact that, under certain conditions and in certain circumstances, electricity is favourable to growth.

In *Structural and Physiological Botany* by Thomé, translated by Dr. Alfred W. Bennett, and accepted as the recognised text-book in the technical schools of Germany, there occurs the following passage:—

“The chemical processes within the cells of a plant, the molecular movements connected with growth, and the internal changes on which the activity of the protoplasm depends—whether exhibited in the formation of new cells

or in motility—are probably connected with the disturbance of electrical equilibrium. The fluids of different chemical properties in adjoining cells, their decomposition, the evolution of oxygen from cells containing chlorophyll, the formation of carbon dioxide in growing organs, and the process of transpiration—all these vital processes must produce electrical currents; *although this fact has not yet been experimentally determined or accurately investigated.*” *

Two of the greatest authorities upon Vegetable Physiology are, or were, Sachs and Strasburger, although equally valuable work has been done by Vines and Green.

Sachs, in his twelfth lecture, said: “That electromotive mechanisms are present in the normal life of the plant itself may be in part directly demonstrated, in part presumed on general grounds. It has been established, for instance, that every movement of water in a tissue, even in the woody mass, is connected with slight electric disturbances; and that these even appear when displacements of water are caused by the mere passive bending of a portion of a plant, or by movements of irritability on its part. In addition we may assume that the chemical processes in nutrition, continually going on in the plant, and the molecular movements during growth and the passage of fluids from place to place, are all connected with electrical disturbances of various kinds, although it has not been possible to demonstrate this experimentally. We may also suppose that in the ordinary life of land-plants especially, during the continually altering differences of electrical tension between the atmosphere and the soil, equalisations take place through the bodies of the plants themselves. The land-plant rooted in the soil offers a large surface to the air by means of its branches, and the roots are still more closely in contact with the moist earth, while the whole plant is

* The italics are mine.

filled with fluids which conduct electricity and are decomposed by currents. Such being the case, it can scarcely be otherwise than that the electrical tensions between the atmosphere and the earth become equalised through the plant itself. Whether this acts favourably on the processes of vegetation, however, has not been scientifically investigated, since what has been done here and there in the way of experiments in this sense can scarcely lay claim to serious notice."

Strasburger—with whom must be associated Drs. Schenk, Noll, and Karsten—has nothing to say upon the subject, and I think it may reasonably be assumed that our knowledge of vegetable electro-physiology is summed up in the extracts I have given.

The analogies, however, which exist in animal and vegetable physiology, especially in the lower forms of life, are sufficiently full of interest to stimulate further research work. That locomotion and sensitiveness are common to low plants as well as to low animals, that marked similarity exists between the animal and the vegetable cell, and that in the matters of the presence or absence of cellulose and the nature of the food required by both organisms there does not appear to be any absolute point of distinction, seemed to me to invite investigation and encouraged me to undertake it. The theory of evolution, enunciated in its present form by Darwin and by Wallace, regards all forms of life as having a common descent, a true blood relationship, whence arises the impossibility of drawing hard and fast lines of separation; and my own results are in perfect harmony with this well-established conclusion.

We know, or at all events it can be demonstrated, that man is a self-contained neuro-electrically controlled machine, dependent for the due performance of his functions upon a constant supply of nerve-energy at a low

potential; that nerve-force is generated in the body with each inspiration, and that the nerve-impulse is neuro-electrical and not chemical. If that is so, and it cannot successfully be disputed, it may reasonably be assumed that in all probability electricity plays a part in the vegetable as well as in the animal world. Investigation has shown the soundness of this theory, as I hope to be able to prove, and further research at the hands of men more capable than myself may lead to far-reaching consequences in the direction of an advancement of our knowledge of practical horticulture and floriculture.

Briefly, the conclusions at which I have arrived are as follows:—

- (1) Everything living, whether animal or vegetable, has a well-defined electrical system; the non-living possessing *capacity* only; and that only in conjunction with moisture.
- (2) Broadly speaking, the edible part of a fruit or vegetable is the *positive* element, or that part which yields a positive galvanometric reaction.
- (3) Dry earth is a bad conductor of electricity, and therefore water is required as an electrolyte as well as being necessary in the formation of protoplasm, etc.
- (4) Every tree, shrub, plant, fruit, vegetable, tuber, and seed is an electrical cell, differing from cells made by human agency in that it cannot be polarised or discharged so long as it remains structurally perfect.
- (5) The skin, peel, rind, or jacket of fruits and vegetables is of the nature of an insulating substance primarily designed for the conservation of their electrical energy.
- (6) The electro-motive force of them all is the same; the current varying in accordance with Ohm's law, *i.e.*, $C = \frac{E}{R}$, where R = the internal resistance.

- (7) Plants grown in pots or removed from the earth and placed in other receptacles differ materially in their electrical constitution from those grown in the earth.
- (8) If a suitable electrolyte, other than water, is mixed with the soil it is possible to grow plants with much less moisture, and
- (9) Growth may be stimulated by means of a continuous current of electricity of low potential and proper sign.

In the experiments of which an account is about to be given the recording instrument was a Kelvin Astatic Reflecting Galvanometer (see p. 285)* of 30,000 ohms resistance at 15° C., and a sensibility of about 4,000 divisions of the scale, at a metre distance, per micro-ampere. My chief difficulty was in the selection of a reliable form of electrode. Those of the non-polarisable variety were, for reasons into which I need not presently enter, deemed unsuitable. Needles were obviously necessary. Platinum was shown by Oliver Heaviside in 1885 * to set up secondary action even in distilled water, and most amalgams were open to the same objection as well as to the suspicion of want of homogeneity. Finally, steel was chosen as the metal, and the electrodes with which more than ten thousand tests were taken without there being one discordant result were darning-needles of equal gauge connected to flexible wires of low resistance. That there are theoretical objections to this form of electrode I am well aware, but, as I propose to prove, they cannot be upheld in face of the evidence to be adduced.

In normal conditions of weather and in countries free from frequent seismic and magnetic disturbances, the Earth is always the negative and the Air the positive terminal of Nature's electrical system.

* *The Electrician.*

Everything, therefore, that grows in the earth is charged by the earth through the roots, and by the air through the flowers and leaves (the lungs, as it were, of the tree or plant), so that in the roots, stem, stalks, and veins the tree, shrub, or plant has its negative terminals, while those parts of the leaves between the veins are positive.

Examination of the vascular bundles and laticiferous vessels of plants will make this clear.

In all fruits and vegetables the negative and positive systems are plainly discernible once the eye has been taught to look for and recognise them.

Before going into detail, however, it will be as well to consider the electrodes.

I found that when two wires of equal gauge and length, soldered to two steel needles of exactly the same gauge and length, were connected to the terminals of the galvanometer and the needles were inserted in various objects and liquids, certain deflections were observed, and that such deflections were not momentary but constant.

These deflections are explained as being due to galvanic action.

There are two theories, *i.e.*—

- (1) Two metals—that is to say, one needle being electrically positive to the other—in one exciting liquid, or
- (2) One metal in two such liquids.

It will, however, be only necessary to consider the first seriously.

Let us suppose that we are using two wires of exactly equal length soldered to two steel needles as before mentioned, and that the object under examination is an apple. In order to settle which is the positive and which the negative side of the galvanometer scale from its central zero, we will first connect the positive or carbon terminal of a dry cell to the right-hand terminal, and the negative or

zinc terminal of the cell to the left-hand terminal of the recording instrument. The resultant deflection is to the right of zero, and we may therefore call the right side of the scale from zero *positive* and the left side from zero *negative*.

Now, if we insert the needle connected to the right side of the galvanometer in the stalk of the apple and the other needle in the flower end, we get a constant *negative* deflection. If that deflection is due to galvanic or chemical action, then so long as we do not alter the connections upon the galvanometer, and reasoning upon the hypothesis that the right needle is electrically negative to the left needle and that chemical action is set up by their contact with the malic acid of the apple, the deflection must continue to be *negative* when the fruit is reversed and the right needle is inserted in the flower end and the left needle in the stalk. Also the signs of both deflections must be reversed if we reverse the wires upon the terminals of the galvanometer. But it is not so; nothing of the kind ever occurs or can occur. Every fruit will give a constant *negative* deflection when the right-hand needle is inserted in the stalk, and a constant *positive* deflection when it is inserted in the flower end; while every tree, shrub, plant, vegetable, and individual leaf will yield a constant *negative* deflection when the right-hand needle is connected with root, stalk, or vein, and *vice versa*. The wires may be reversed upon the terminals of the galvanometer as often as desired. There will be no difference whatever in the phenomena observed. In the case of pot-grown plants and fruits, etc., polarity is reversed because the moist soil in the pot receives its charge from the positive air instead of from the negative earth.

If, however, diffusion takes place by reason of injury or decay, and the plant, vegetable, fruit, or leaf becomes rotten, *no reversal of sign will be obtained*.

ELECTRICAL STRUCTURE AND

THE APPLE.

Fig. 1 illustrates the electrical structure of the apple. The stalk, receiving its negative charge from the earth, communicates directly with the negative core, which, as will be seen, is insulated from the positive or edible portion. The core terminates at its upper end, it will be observed, in a dry plug—the remains of the flower—while the stalk is always sealed, either by dry fibre or by a gummy or resinous secretion. The rind or outer covering is of enormous resistance, and is evidently designed to conserve the energy of the cell by giving it high absolute insulation.

From Fig. 2 we gather some idea of the means adopted by Nature to prolong life.

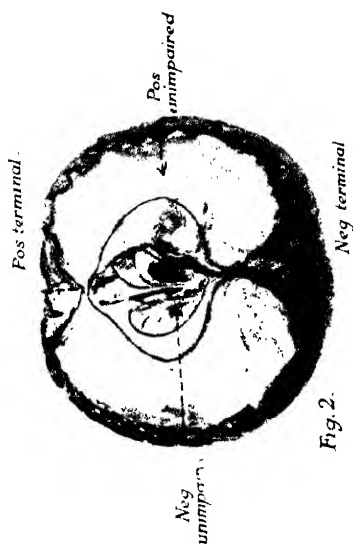
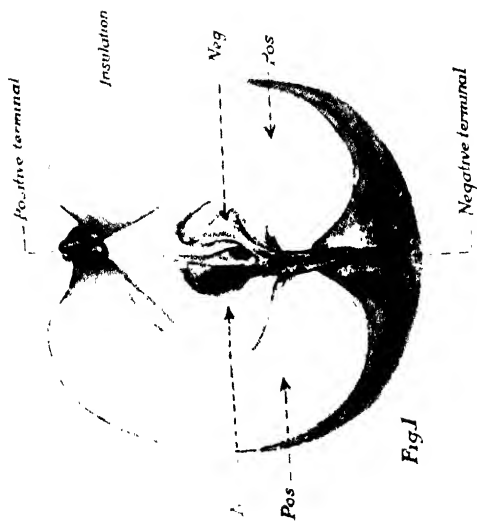
In the example shown, seven days had elapsed since the division was made, the surfaces had partially dried, probably to increase their resistance and lessen liability to evaporation, the walls of the core had similarly hardened, and the rind or peel had closed round the edges to, we may assume, prevent the loss of any of the juice necessary to the apple's continued electrical activity.

The pear and the quince so nearly resemble the apple that it is unnecessary to describe them. The only difference is that the core is more elongated in shape and is placed at a slightly greater distance from the stalk than in the case of the apple.

THE BANANA.

It will be seen that the negative terminal—the stalk—is connected with the skin and an inner lining from which the positive flesh of the fruit is instantly detachable. Nowhere does there appear to be any actual electrical contact between the negative and positive systems except, possibly, by osmosis—the flesh being enclosed in an envelope—and as the whole of the flesh is positive the dietetic value

The Apple



Note:- Showing what occurred seven days after the cut was made. The surface had partially dried, to get better protection, the walls of the core had hardened and dried and the rind had closed round the edges of the cut to prevent the loss of any of the juice necessary to the Apple's continued existence.

The Banana

*Note: All the fruit is positive
with the exception of
the Stalk and Skin.*

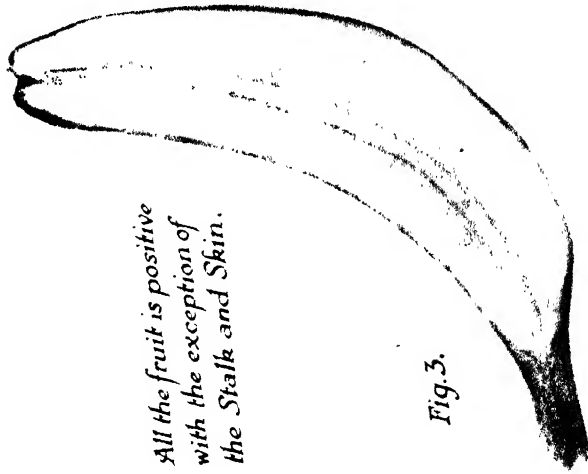


Fig. 3.

*Showing the protective
lining of the
Inner (Negative) Skin.*

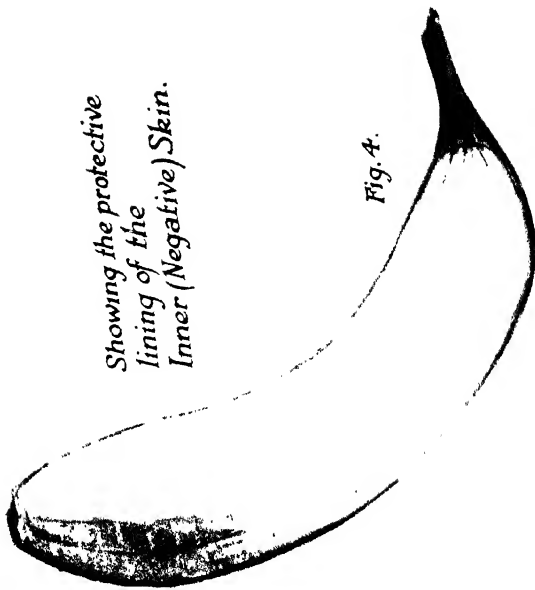


Fig. 4.

The Tomato



Positive terminal



Fig. 5

Sectional Plan of A B

The Orange

As terminal

Protective material

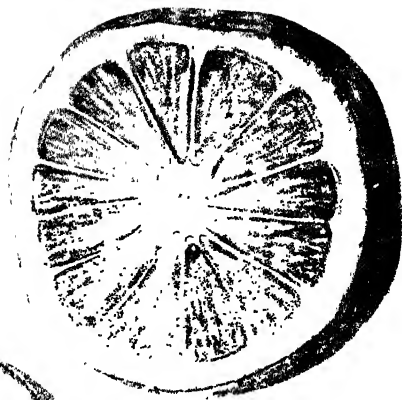
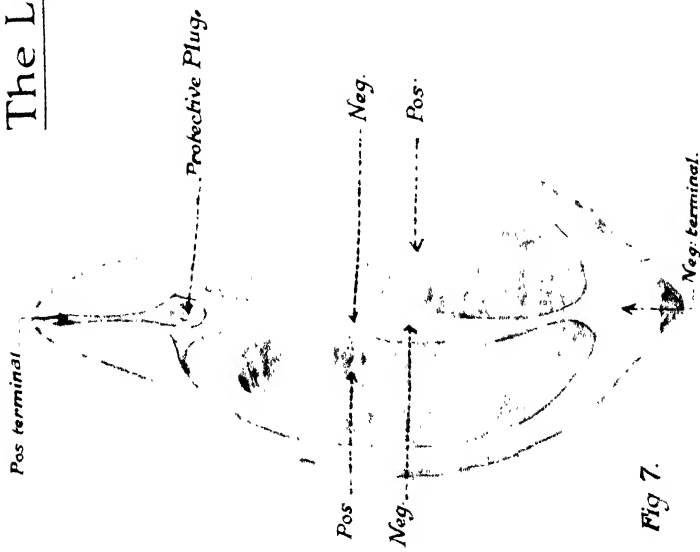
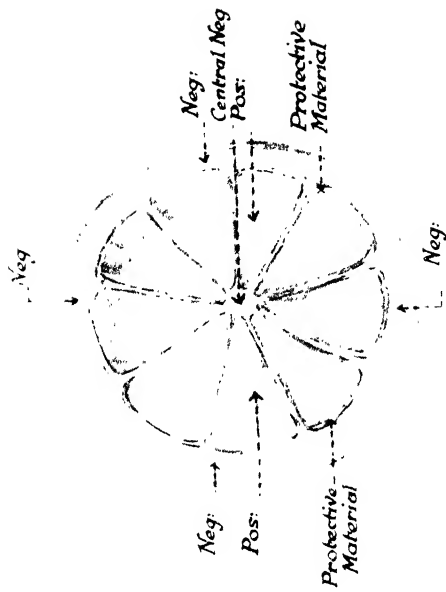


Fig. 6

The Lemon



Sectional Plan



of this fruit should be high. Unfortunately it has when ripe, and probably owing to its porous skin, a comparatively low insulation resistance and therefore a short life. Figs. 3 and 4 will serve to illustrate the points mentioned.

THE TOMATO.

The tomato (Fig. 5) affords us convincing testimony of the reliability of our electrodes, because during the late summer we can take one grown in the open ground and one from the greenhouse and test them under exactly the same conditions and at the same time. That grown in the open ground will be found to be negative at the stalk and positive where the flower originally appeared, while that from the greenhouse, where it had been deprived of its



supply of current from the negative earth and compelled to take its root-charge from the positive air, assumes an opposite polarity and is *positive* at the stalk end, etc. These remarks apply to all fruits and vegetables cultivated alike in the garden and in pots in the greenhouse, such as the cucumber, the orange, lemon, etc., etc.

But if the soil in the pot is connected by a metallic conductor with the earth (*see illustration*), no change of polarity will occur.

THE ORANGE, LEMON, GRAPE-FRUIT, ETC.

In testing these fruits great care has to be exercised owing to the large quantity of juice they contain, the rapidity of its action upon steel, the danger of diffusion, and the extreme delicacy of cells of which the fruits are mainly composed and the narrow contacts they offer. Their structure, electrically considered, is best explained by Figs. 6, 7, and 8, but especial notice should be taken of the wonderful manner (shown in the sectional plans) in which the positive flesh of the fruit is surrounded by protective material, and how that protective material is connected in turn with the central and outer negative system. Nor is their absolute insulation provided for in a less remarkable manner. The skins of the orange and lemon in particular appear to be porous, but in reality they are built up of innumerable cells containing a highly-resistant ethereal oil which, until expelled by evaporation, conserves their energy.

THE TURNIP

(Swede and Mangel-Wurzel, etc.)

In Fig. 9 it will be seen that the negative system of this vegetable extends from the root along the outer perimeter and to the whole of the thickness of the rind. The inner lining of this—an envelope, as it were—is probably protective material, and, so far as I am able to judge, the whole of the interior is positive; that system extending to the positive terminal, or flower end; and to those portions of the foliage free from stalks and veins which connect directly with the negative system.

From an electrical point of view the turnip compares unfavourably with many other vegetables. At no time

The Turnip



Fig. 9

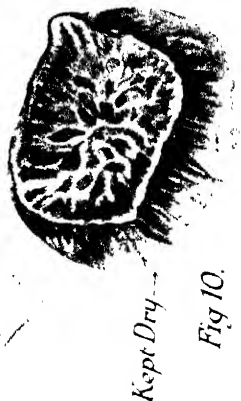
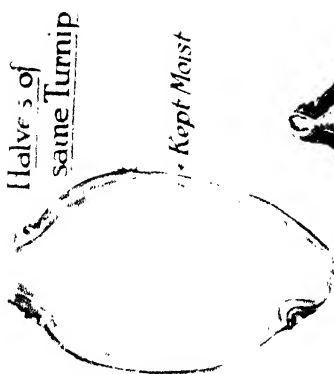
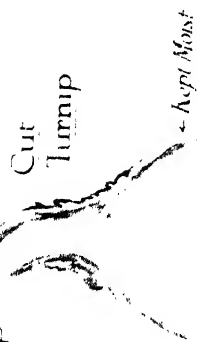


Fig. 10.

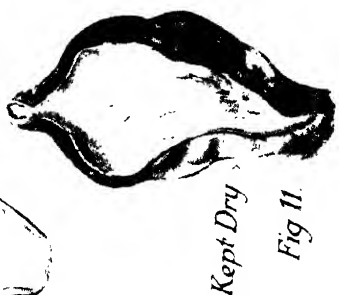


Fig. 11.

The Onion.

Positive terminal

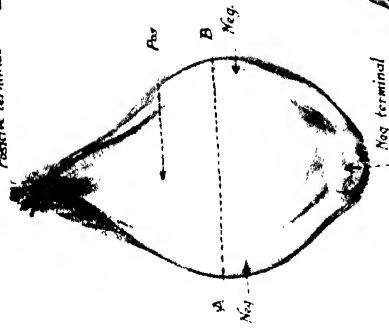


Fig. 13.



Sectonal Plan at A.B

The Carrot



Pos

Neg

Pos



Neg

Note The roots encircle but are not in Electrical contact with the Central positive system. shown by the darker lines. The lighter plug at the top of the latter is probably protective material

Fig. 12.

is its skin or rind of very high resistance, and when a turnip is divided—as in the illustration given—it soon, especially if kept in a dry place, becomes unfit for food. Unlike some other vegetables, such as the potato, it does not appear to be provided with the means of forming fresh insulating material upon the cut surface, with the result that it dries up, and, not being able for that reason to absorb charge from the air, loses its electrical activity and degenerates into a spongy, fibrous, and inedible mass. If, however, it is kept in a moist condition it retains capacity, or power of absorption of electricity from the air, and can be preserved for a longer period of time. This was ascertained by cutting turnips in halves. Figs. 10 and 11 show the halves of two turnips taken from the same bunch. That given in elevation was kept under water for ten minutes three times daily, while the other (sectional plan) was left untouched; both being subjected to identical atmospheric conditions. In the same figures we have the two halves of the turnip in elevation. These were treated as above, and in both instances were sketched after an interval of eight days. They call for no further comment from me.

THE CARROT AND PARSNIP.

Fig. 12 sufficiently illustrates the electrical structure of these vegetables, but attention may be drawn to the fact that the roots are connected directly with the negative, and that the central positive system is insulated or protected from the former in the manner shown. If these vegetables are divided in the middle, lengthwise, the negative can be separated from the positive portion with the fingers, leaving the latter exposed as a tongue and exhibiting the former encircled by root-filaments.

THE ONION.

This is an unusually difficult vegetable to test, in that while the bulb appears to form a complex cell, the intermediate contact-spaces are so narrow and the liability to diffusion so great, when the onion is divided, that I am unable to speak with certainty. Botanists, however, will readily solve the problem, which, from an electrical standpoint, is to differentiate the layers connected with the root from those in alignment with the tubular leaves. The former will be negative and the latter positive.

Fig. 18 depicts the structure of the onion as it is presented to the unaided eye and in so far as I am able to determine it galvanometrically. The negative system seems to extend from the root to the outer second and third layers of the bulb, between which and the central positive system there exists a membranous and probably protective lining. The contacts afforded by the poles are well defined, the absolute insulation is extraordinarily high, and altogether the onion is a vegetable cell of a very perfect description. Its electro-motive force is, approximately, 0.086 volt; the current varying, of course, with size. Such a cell is invaluable in the testing-room for such work as, for instance, taking the constant of a sensitive galvanometer or comparing deflections from living muscle or tissue, instead of using for the purpose a standard cell liable to polarisation when employed without very high resistance in circuit.

TUBERS.

These differ in their electrical constitution from root-vegetables proper and from fruits, in that they are not merely bipolar, but have a number of positive and negative terminals. I have taken two examples, *i.e.*, the potato and the Jerusalem artichoke, reserving others for future investigation.

The Potato

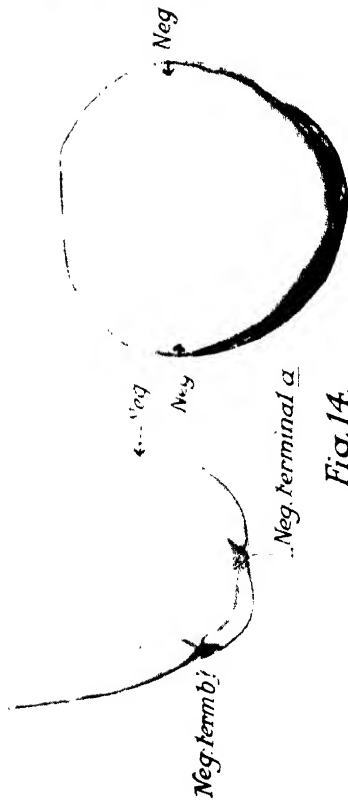
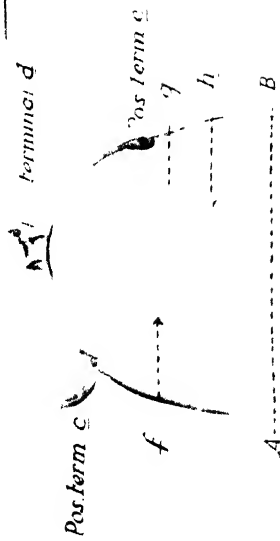


Fig. 14.

Sectional Plane at A B

growing from the Prolific Eyes. —



Fig. 15.

Jerusalem Artichoke.



Fig. 16



THE POTATO.

The potato plant receives its supply of current direct from the earth, but it is open to doubt whether such is the case with the tubers to which it gives birth. They are connected with the parent plant by a filament or filaments—not altogether unlike the umbilical cord of the human—through which or by means of which they are energised. In the potato shown in Fig. 14 I can trace only two eyes to which such filaments might have been attached (marked *a* and *b*). They are negative terminals, communicating with the outer negative system, while *c*, *d*, and *e* are terminals (positive) of the lines *f*, *g*, and *h*. It is only when these slightly darker lines reach the jacket that we find a live or prolific eye. The unprolific eyes, so called, are those by which the tuber is attached by a filament or filaments to the parent root.

It has been seen that some fruits seek to protect themselves when cut or injured, or rather that Nature has made in that regard some provision for them.

In this respect the potato is well endowed. Very shortly after being cut it exudes a starchy substance which dries rapidly, and forming a film over the cut surface, restores in some measure, if not entirely, the impaired insulation, as well as preventing loss, by evaporation, of the fluid, without which it must become electrically dead. This tuber will, in fact, keep longer and grow better after being injured than any other member of the vegetable world with which I am acquainted, other things being equal.

THE JERUSALEM ARTICHOKE.

There are several points of difference between this tuber (Figs. 16 and 17) and the potato. It is covered with root-filaments, is distinctly bipolar as regards the ends, and does

not appear to be provided with so efficient a repair outfit. In common with the potato, it has a marginal negative system and several positive terminals, but I should imagine, from the number of root-filaments, that instead of being dependent upon the mother-plant it derives its electrical supply directly from the earth.

LEAVES.

I selected a few examples from evergreen and deciduous leaves with a view to seeing what difference, if any, existed between them as regards relative conductivity, the ramifications of their negative systems, and the quality of the main conductors—the stalks—through which current is conveyed to them from the earth.

As a rule, in deciduous leaves the veins do not seem to me to form so complete and extensive a network as in those of the evergreen variety. They are, moreover, not so well insulated, are thinner in texture, and, if they lose their moisture under the influence of prolonged summer heat, become electrically inert and fall. Such a leaf is that of the horse-chestnut (Fig. 18), and it offers a sharp contrast to that of the ivy (Fig. 19), in which the negative veins form an almost complete network, and which carries three principal veins as against the single one of the horse-chestnut. The leaf is also more substantial, is infinitely better adapted to retain its moisture, and therefore its conductivity and capacity of electrical absorption, while the walls of the veins appear to possess high resistance, or, in other words, a high degree of insulation; the intermediate or positive parts of the leaf being able in the presence of occasional rain or even a damp atmosphere to receive positive charge from the air.

This perfection of insulation and inherent interior moisture extend to the stems of the plant, so that, their

Horse Chestnut
Leaf

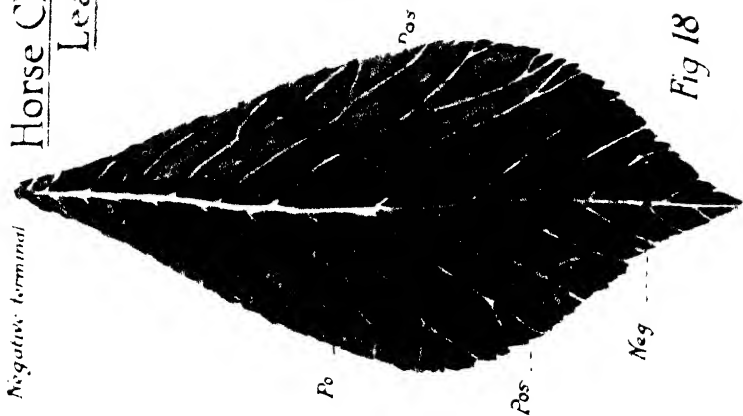


Fig 18

Ivy Leaf

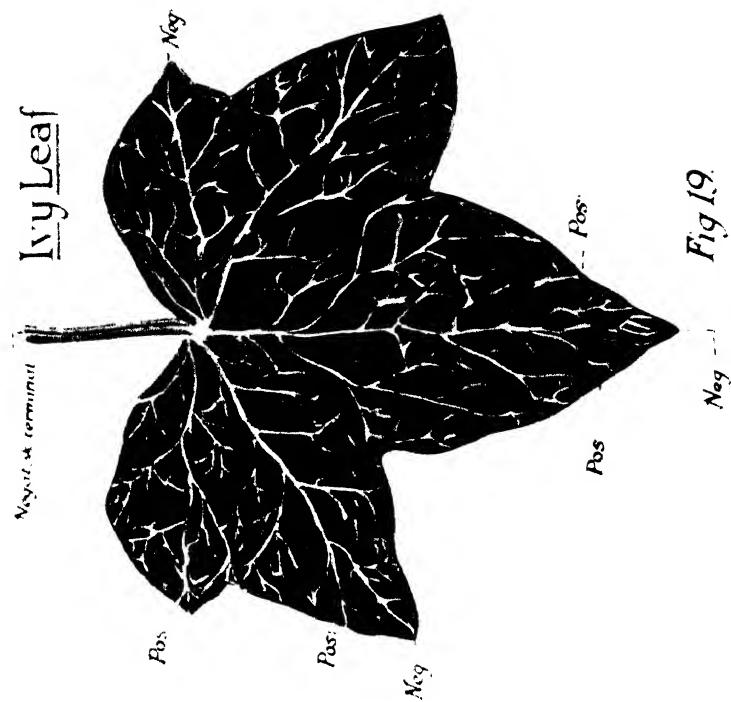


Fig 19

Electrically Stimulated
Onion
"A"

*Zinc to root. Carbon to
foliage end. 5 days*



*Note the black marking
is due to electrolysis.*

Fig. 20

Electrically reared
Onion
"B"

*Zinc to foliage end. Carbon
to root; 5½ days; no
growth.*



Fig. 21.

Electrolysis

internal resistance being unusually low, a current in excess of the average is carried by them, and may possibly explain, in some measure, the ivy's tenacious hold upon life. The insulation is probably due to the numerous resin-passages found in the plant.

DO VEGETABLES AND FRUITS POSSESS CAPACITY ?

The answer to this question, so far as the experiments have gone, is in the affirmative. No attempt has been made to determine, by comparison with a standard condenser, the electrostatic capacity of any vegetable or fruit, as the conditions would vary enormously with size, degree of moisture present, and insulation resistance, without offering adequate compensation for the labour involved.

It was therefore thought sufficient to ascertain if fruits and vegetables when put in circuit with a battery and a recording instrument, merely, by reason of their conducting juices, formed part of a simple circuit, or whether after the battery had been disconnected they retained charge : whether by reversing the polarity of the battery the polarity of the object under examination could be altered, and for how long any such charge or change, if any, was observable.

The first experiment was with a quince. With the right-hand needle inserted in the stalk and the left needle in the flower end it gave a constant negative deflection. The needles were allowed to remain in the fruit, but the wires to which they were attached were connected to a dry cell for five minutes, *i.e.*, right needle to carbon and left needle to zinc. The resultant deflection was strongly *positive*, discharge took place slowly, and it was a considerable time—unfortunately not recorded—before the original *negative* deflection was restored.

At a later date I tested a number of fruits and

vegetables, using a reflecting galvanometer of the D'Arsonval type.

In every case the connections were as shown by Fig. 21A, the needles, except where otherwise mentioned, being left in the object under examination during the whole of the test. The scale limit was 250 mm. from a central zero. In every case, also, the fruit or vegetable gave, with the

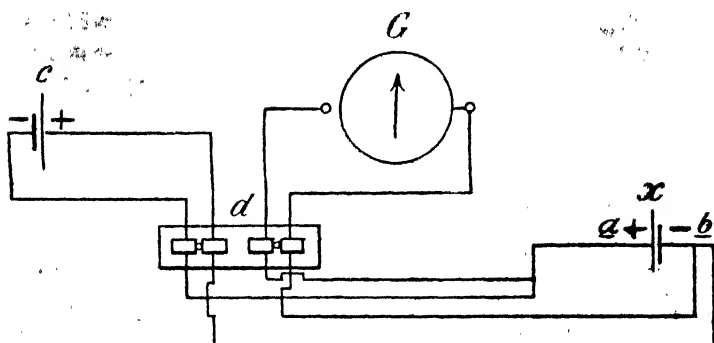


Fig. 21A.—CONNECTIONS IN CAPACITY TESTS.

- x = vegetable cell.
- a = positive terminal of same.
- b = negative " "
- c = dry cell 1.5 volts. " "
- d = plug switch.
- G = galvanometer.

right needle inserted in the stalk end, a constant off-scale *negative* deflection.

It is not proposed to give full details, as they might become wearisome, but to summarise the results obtained in each test or series of tests.

THE ONION.

With the right needle to the root and the left needle to the foliage end it gave a constant, fairly rapid, off-scale *negative* deflection. Five minutes' charge from a cell of 1.5 volts—positive to root and negative to foliage—merely

reduced this deflection, and it was necessary to give a further five minutes' charge. At the end of this time it went rapidly off-scale *positive* and remained off-scale for fifteen minutes. The connections were then earthed for five minutes through 5,000 ohms, when the charge was found to be dissipated and the true polarity restored.

In a second experiment with the same onion a further ten minutes' charge was not fully discharged until forty minutes after the first reading.

A STICK OF RHUBARB.

This was charged for five minutes and the cell disconnected. The deflection was then off-scale *positive*. Five minutes later it had fallen to 160 mm. positive, and at the end of the tenth minute risen to 180 mm. As this might have been due to the effect of the juice upon the electrodes, these were removed, cleaned, and carefully reinserted, when D = 180 mm. positive, rising in a further five minutes to 250 mm. Five minutes E, however, removed the charge and the original polarity returned.

THE APPLE.

This fruit was large, ripe, and in perfect condition, and exhibited an unusual quantity of current. Ten minutes' charge with 1.5 volts merely reduced the deflection to 50 mm. negative. I therefore gave it another five minutes, when D = rapidly off-scale *positive*. Ten minutes later—it being still off-scale—the connections were put to E for five minutes and the electrodes removed and cleaned. D was then 250 mm. positive and five minutes later 285 mm. positive. It had then, unfortunately, to be left—insulated—until the next day, when it had fully recovered.

THE BANANA.

This was really a small plantain, about 7 in. long. After ten minutes' charge $D =$ rapidly off-scale positive; five minutes later it was 190 mm. positive, and in twelve minutes thirty-five seconds more had gone off-scale negative, that is to say, had fallen 440 mm. It did not, however, quite regain its original polarity until it had been short-circuited through 5,000 ohms for a further twenty minutes. Even so it discharged itself in twenty-eight minutes as against forty-one minutes of the onion, and this I attribute to its comparatively low absolute insulation resistance.

THE TURNIP.

I took two examples of this vegetable. The first was oval in shape, weighed 3 oz., and had been kept in a dry room for a week, both poles being dry and fibrous. The second was an almost perfect sphere, $10\frac{1}{2}$ in. in circumference, weighed 10 oz., and had been recently pulled. The root was not dry, the foliage end white and exuding moisture. No. 1 was charged for ten minutes as before, when $D =$ very rapid off-scale *positive*. Short-circuited through 5,000 ohms it remained off-scale for thirty-two minutes, and did not regain its former polarity for thirty-three minutes more, showing a slow discharge, but one, after allowing for higher insulation, not inharmonious with the preceding data. Upon examination the right needle was found to be blackened by electrolysis; the left needle having traces only.

No. 2. Ten minutes' charge, as before.—Immediate $D =$ very rapidly off-scale *positive*. In three minutes the light returned to 250 mm. positive, and in six minutes more had gone off-scale *negative*; the vegetable recovering

polarity almost instantly. The right needle was quite blackened and the left needle clean. As this discordant result might have been due to leakage through the moist poles or terminals of the vegetable, I painted both with a non-conducting solution and allowed it to dry, in order to see if higher insulation would slow down the rate of discharge.

The experiment with No. 2 was then repeated under the same conditions but with fresh points of contact.

After ten minutes' charge D = very rapid off-scale *positive*. The vegetable then remained short-circuited through 5,000 ohms. D continued off-scale for seventeen minutes, when the vegetable was accidentally knocked over.

No. 2 (third experiment).—The connections were put to earth until the vegetable regained polarity and gave perfect reversals. It was then charged for ten minutes with 1.5 volts, when D = very rapid off-scale *positive*, not falling to 250 mm. positive until sixteen minutes later. The period of fall from 250 mm. positive to 250 mm. negative was eight minutes, and ten minutes later the vegetable had recovered. The conclusion, or one conclusion, to be drawn is, of course, that absolute insulation is a factor of primary importance in retention of charge.

THE ORANGE.

Circumference $8\frac{1}{2}$ in., weight $5\frac{1}{2}$ oz. After ten minutes' charge D = fairly rapid off-scale *positive*. In ten minutes it fell to 250 mm. positive, and in fifteen minutes more the light had reached 250 mm. *negative*; the fruit regaining its former full polarity fifteen minutes later. The right electrode showed a mere trace of electrolysis. The charge in this case remained on the positive side of the scale for nineteen minutes, but the absolute insulation of the orange and lemon is not very high.

CHAPTER II

SOME SEEDS IN THEIR ELECTRICAL ASPECT

So far I have not been able to find time to study the electrical problems presented by germination, but I am convinced that when this is done even greater proofs of the universality of the law will be forthcoming. The subject is a sufficiently vast one to call for more than the labours of one man and the compilation of one book, but, so far as I am concerned, it must be reserved for future investigation.

The examination of seeds in their various stages of development present features of interest which cannot fail to claim the attention of the student, and although my opportunities for observation have been limited by a variety of circumstances, I am glad to be able to offer some food for thought and, I hope, additional stimulus to research.

During our consideration of the nature of the nervous impulse we, or at all events some of us, learn that in the case of the human foetus independent existence is only begun when air (oxygen) is first taken into the lungs and complete circulation established—until that moment the child is dependent upon the maternal blood-stream—and will note, in the chapter upon Cell-reproduction, that the so-called “resting” stage of a cell is really a developing stage. That being so, it follows, I think, logically, that while a seed is still attached to the parent plant or tree it is equally dependent with the unborn child, and that the

FUNCTION IN PLANT LIFE

same law which governs cell-division should guard the immature seed from the possibility of premature germination by withholding from it a perfected electrical system. Unless that is so there is a flaw in our reasoning, or our understanding of the law is at fault.

THE HORSE-CHESTNUT.

At the time of year of the experiments about to be described (September) and for the following few weeks the seeds were in various stages of development, and could be studied at leisure. The method adopted was to cut the pods in halves longitudinally and test them galvanometrically, to ascertain the relative sign and electrical activity of their various parts. The following photographs are illustrative of the result:—

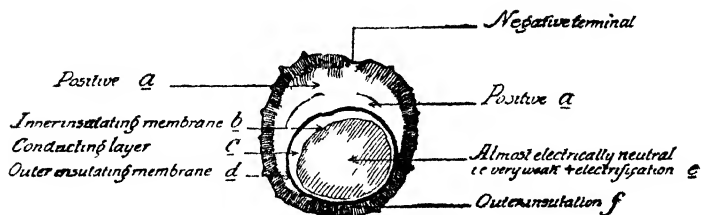


Fig. 22.—SECTION OF HORSE-CHESTNUT [Original. photo.]

a, *a*, part, consisting of white, pithy substance, which is positively charged; *b*, insulating membrane immediately enveloping the seed substance; *c*, conducting layer, negatively charged; *d*, insulating membrane enveloping the conducting layer; *e*, seed substance yielding only a few millimetres positive deflection as against the 1,000 mm. negative of the conducting layer; *f*, outer insulation, porous, and of low resistance.

The next photograph shows the negative terminal and system more clearly, and gives a better idea of the extent of the positively charged material. This seed is not in

such an advanced stage of development as the preceding one, and the pod contained two seeds.

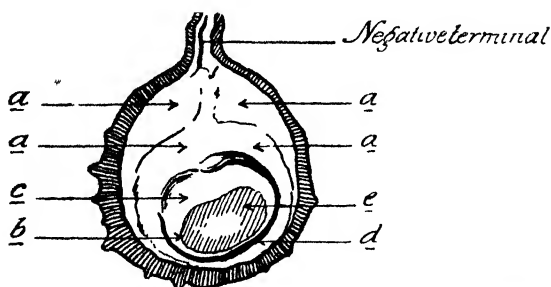


Fig. 28.—SECTION OF HORSE-CHESTNUT. [Original photo.]

Two insulating membranes are shown, but there is a third, not adherent to the seed, but lining the cavity in which it lies, and designed, there can be little doubt, to prevent a positive charge from reaching the immature seed; inasmuch as this membrane appears to be formed before the membrane *d* attains the required resistance. The function of the other two membranes, *b* and *d*, enclosing the actively charged conducting layer, *c*, calls for more elaborate if hypothetical explanation.

Apart from the seed itself the major portion of the pod is taken up by a white, pithy substance of positive sign; probably charged by the air through the epidermal spines or pores. While the seed is growing it does not, I imagine, require direct, but rather modified, electrical stimulus. From the seed substance itself I obtained deflections of a few millimetres only, whereas the conducting layer, *c*, gave excursions of one thousand and over. Assuming, then, that for some wise purpose—possibly to give adequate time for development—stimulus to the seed substance is modified, the function of the conducting layer, *c*, becomes apparent, inasmuch as it would play much the same part

as the lymph space on a nerve-fibre or the copper taping on an insulated wire in preventing an induced charge from passing it.

Now the part *a*, *a* is positively charged by the air and has greater surface area than the conducting layer *c*. We should therefore find—as we do find—that the tension of *c* is in excess of that of *a*, *a*, and that the sign is negative instead of positive.

That is while the seed is still attached to the tree and has no separate and independent existence.

But in course of time the pod falls and releases the seed by splitting segmentally. The latter we must suppose to be planted or buried in the soil and to be thereafter dependent upon the earth, as man is mainly dependent upon the air as the source of electrical energy. Obviously, then, some change must take place to enable the seed to survive, and that change is a very important one. *The conducting layer, c, dries up*, and therefore ceases to intercept charge, but the outer membrane, *d*, after contact with the damp soil, would become a conductor, and without the inner membrane, *b*, no electrical system could obtain. But with *d* as a conductor and *b* as the insulating material, induction could take place, and the seed substance receive a positive induced charge in the following manner—

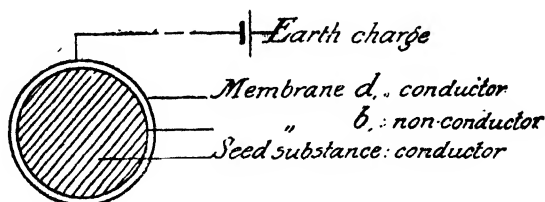


Fig. 24.

so that the two membranes are necessary both while the seed is in the pod and after it has been released.

Fig. 25 shows the final appearance of the membranes

d and *b*. It is, however, not improbable that instead of the whole of *d* becoming conductive, only the part *g* illustrated by Fig. 25 may so function. This is suggested by the greater desiccated space between the membranes at that point. But even in that event the only material difference, so far as I can see, would be that the tension of *e* would be lower than that of *d* by reason of the larger surface area of *e*.

Prior to the completion of the insulating system the conducting layer *c* seems to receive charge directly through the stalk of the pod. During such time, therefore, the part *g*, or the depression marked *h* thereon (Fig. 26), would probably be the point of contact.

Fig. 25.—SECTION OF HORSE-CHESTNUT SEED.

Showing the final appearance of the membranes *d* and *b*.

[Original photo.]

As regards the unusually elaborate insulation of the pod and seed of the horse-chestnut, it is worthy of remark that the secretion both of the white, pithy material and the seed substance is markedly acid, staining steel and instantly turning litmus-paper red. Neither of the three



Fig. 26.—HORSE-CHESTNUT SEED. [Original photo.]

The part *g* occupies about one-third of the area of the membrane *d*; *h* is a small circular depression upon *g* and is probably of the nature of a contact before the insulation is completed.

membranes, however, has any effect upon litmus-paper, and, so far as I could determine, all are, as one would expect, chemically neutral.

Fig. 27 gives another view of the dried-up layer, *c*, and shows a tongue-like projection of the seed substance

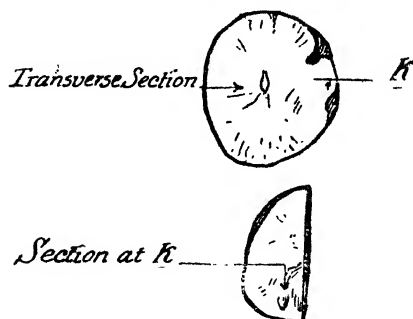


Fig. 27.—SECTIONS OF HORSE-CHESTNUT SEED.

[Original photo.]

Showing projection of seed substance.

This tongue-like projection, *k*, does not connect with *h*, nor is it so pointed as in the edible chestnut; more frequently it resembles the end of a dumb-bell when cut in section transversely. The part *g* is assumed, in this instance, to be the bottom of the seed.

similar to that of the edible chestnut and insulated by the inner membrane *b* in the same manner. The probable purpose of this is suggested later on.

A CONTRAST.

I had before me, uncut, an edible and a horse-chestnut, both in pod. They were free from spines, were of the same colour, size, and shape, and there was nothing in their outward appearance to differentiate them, except that upon one the stalk still remained, to remind me that it was the horse-chestnut. I cut the latter in halves, as before, and photographed it. As it was in all its details exactly similar to Fig. 22 there is no need to reproduce it. I then proceeded to treat the

EDIBLE CHESTNUT

in the same way, and photographed the two separate halves, shown in Figs. 28 and 29. The difference is very

remarkable. At all stages of development of the horse-chestnut the seed substance is solid, and fills the whole of the space within the inner membrane *b*, as shown in Fig. 22, but in the edible chestnut it is more suggestive of a foetus in the womb. I have cut some pods (unfortunately not now available for reproduction) in which the seed substance appeared in semicircular shape, and offered a weird resemblance to the foetus at a very early period of its growth. Apart from that, however, there are other essential points of difference. Both in the horse-chestnut and the edible variety the secretion is markedly acid, but whereas in the first the seed substance holds very little liquid, that of the second is so heavily charged with it as to fill or almost fill the cavity *i*, when the pod, and with it the seed, is divided.

In the case of the horse-chestnut the cut surface of the seed soon discolours and becomes a brownish-yellow; that of the edible chestnut remains white for a much longer time, although the conducting layer *c* dries up almost immediately. One is a seed, pure and simple; the other is both a seed and a food.

As will be seen in Figs. 22 and 28, the construction electrically is much the same in both seeds, but whereas in the horse-chestnut the seed substance is closely adherent to the inner membrane *b* throughout, only a small portion of the seed substance of the edible chestnut, in the posterior part of *j*, is in its adolescence adherent to it, and this part, as in the horse-chestnut, penetrates or protrudes through the inner membrane by means of a tongue-like projection to the limit of the conducting layer, *c*, which is thicker than in the horse-chestnut seed. It, however, does not connect with *g* (Fig. 25), but is nearer the centre of the seed (*g* being, in the photograph, rather high up on the left). This tongue is enveloped by an insulating membrane, by which it is separated from the layer *c* and the outer

membrane *d*, and may be designed to facilitate induction between the conducting layer and the seed substance, inasmuch as the latter, unlike the horse-chestnut, is not adherent to the inner insulating membrane *b*, except at this point. Two considerations at least present themselves. Capacity in the case of vegetables and fruits is governed by the nature and quantity of the conducting liquid as well as by the specific inductive capacity of the dielectric, and the area of the respective plates or discs or membranes and their distance from each other; *and upon capacity* plus absolute insulation the life of the vegetable or fruit depends. In the horse-chestnut—assuming specific inductive capacity and absolute insulation to be the same in both—we have the plates of comparatively large area and close together, but with very little moisture. In the edible chestnut one of the conducting surfaces, *i.e.*, the seed substance, is irregularly shaped, is removed in youth—except at the posterior part of *j*—from the membrane *b*, but contains a large quantity of moisture; is, in fact, surcharged. Actual test showed the tension of the seed substance to be higher than that of the horse-chestnut, and this would be in accordance with established laws.* But what is the purpose underlying it?

I may be wrong, but a possible explanation presents itself.

Let us suppose that the horse-chestnut seed, not being intended for food, is destined only to ripen, to fall from the tree and pod, and to be buried in the earth to reproduce its species.* That would seem to be the sole object of its creation, and nothing but the perfection of its insulation would equip it with a sufficiently robust constitution to enable it to survive prolonged exposure under conditions unfavourable to germination.

* See chapter on INDUCTIVE CAPACITY.

The edible seed, on the other hand, must, if it is to be useful as a food, have keeping qualities, be able to preserve

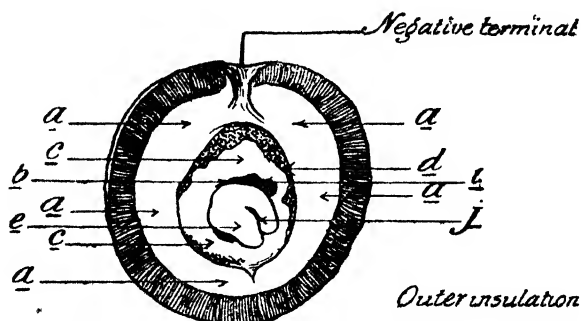


Fig. 28.—SECTION OF EDIBLE CHESTNUT. [Original photo.]

a, a, a, a, a = positively charged white, pithy substance; *b*, inner insulating membrane; *c* = conducting layer; *d* = outer insulating membrane; *e* = seed substance; *j* = beneath this is the tongue-like projection; *i* = cavity in which the seed substance is ensclosed.

itself unimpaired for a considerable period of time, and in this we may find a reason for the quantity of moisture with which it is, under considerable pressure, charged. But

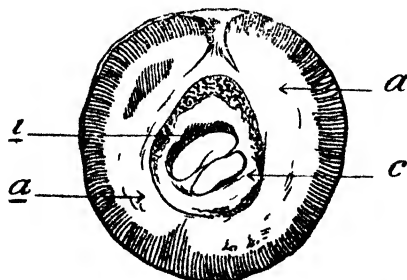


Fig. 29.—SECTION OF EDIBLE CHESTNUT: THE OTHER HALF.

[Original photo.]

The seed substance seen in the central cavity is not attached in any way to it. Before division of the pod it formed, of course, part of the seed substance shown in Fig. 28.

it is also a seed, and when it is planted in the soil and the outer membrane—or some portion of it—becomes a

conductor, we have, although in a slightly different form, the same electrical arrangement as shown in Fig. 22; the membranous covering of the tongue of the seed substance providing the dielectric and the seed substance itself the inner or second conducting surface.

It is worthy of note that in the edible chestnut the white, pithy, positively charged area is larger—other things being equal—than in the horse-chestnut, and this might account for the conducting layer, *c*, of the first taking, as is the case, a higher negative charge than obtains in the second. It may also explain the slightly increased positive electrification of the seed substance of the former.

As regards what I have termed a “repair outfit,” both the horse and the edible chestnut exude upon their cut surfaces what bears the appearance of a starchy secretion. This dries, and not only checks further evaporation of moisture from the seed substance, but to some extent restores the lost insulation. In the potato the phenomenon is particularly noticeable, and the film is very quickly formed. With the chestnuts the process is slower, but is a protective measure of the same order. It would be interesting to see whether in this case division of the seed prevents germination.

Another matter to which I should like to call attention is that when freshly cut, the seed substance of the ripe horse-chestnut is cream-coloured, or rather white, with a faint tinge of lemon-yellow. After exposure to light, and as soon as the starchy film develops, the cut surfaces become yellowish-brown, with a deeper tint of yellow showing beneath. This is, no doubt, a matter of electro-chemistry, and as such somewhat beyond my purview, but the suggestion has occurred to me that it may be a measure of protection against actinic rays, or changes conceivably introduced by them.

ELECTRICAL STRUCTURE AND

THE ACORN.

A beautiful simplicity characterises this seed, and one might well believe that from it was borrowed the principle of the modern incandescent electric lamp-holder.

As will be seen from the example given in Fig. 80, the cups in which the acorns are seated are joined up, as it were, in series, while the negative terminal is in the form of a circle, *a*, at the bottom of the cup; the seed carrying upon its posterior part a circular protuberance, *b*, which seats exactly upon the contact *a*.

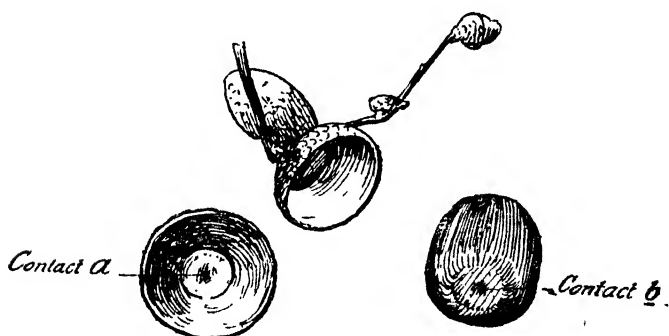


Fig. 80.—ACORNS.

[Original photo.]

Electrically considered, the acorn is similar in construction to the horse-chestnut seed. There are three insulating membranes, and the secretion of the seed substance is also distinctly acid. It should have a fairly long life owing to the excellence of its absolute insulation, to the ample provision of moisture, and to the fact that it can take in positive charge from the air through the point at the apex of the seed.

In common with other seeds, such as the Barcelona nut, etc., there are sometimes two seeds within the shell.

When that happens and the acorn is cut in halves longitudinally it presents the following appearance:—



Fig. 31.—DOUBLE ACORN IN SECTION.

The sides and lower surfaces of 1, 2, 3, 4—the cut surfaces only being exposed—are sheathed in insulating membranes, which extend to and cover them from the inner part of the contact *a* after the acorn has ripened.

COB-NUTS.

After discovering that Nature had, for a reason not yet understood, joined up acorns in series, one remembered that other things with which we are familiar are connected either in multiple arc or clusters in series. The cherry, with three or more stalks tapped off a main contact, is an excellent example of this, and I wish I had sketched or photographed a group of them when they were in season. Fortunately, however, we had not to look far for other specimens of the Great Electrician's craft. It was the time of year for cob-nuts, and the cluster shown in Fig. 32 served to illustrate one method of connecting which appears to be in the above category. The main lead, the stalk, it will be noticed, is unusually thick. It carries current to supply four nuts, and if we imagine them to be incandescent lamps instead of nuts we know we should have to make similar arrangements for their supply.

Where it joins the base of the cluster, as photographed, the stalk splits into four branch leads, each of which connects with a cup not unlike that of the acorn, but outwardly continuous with the foliage, into which the nut fits

AND

to make contact at its base. This, however, is not small as in the acorn, but extends to the whole of its posterior part. The cup, however, as shown in Fig. 33, is not



Fig. 32.—CLUSTER OF COB-NUTS. [Original photo.]

continuous with the foliage, but is insulated from it by a fibroid layer which separates it electrically from the negative terminal or lead.



Fig. 33.—FOLIAGE AND CUP OF COB-NUT OPENED OUT. [Original photo.]

A longitudinal section of the ripe nut reveals much of interest. The secretion is only slightly acid, and insulation is regained in this instance by the rapid exudation of a wax-like secretion upon the cut surfaces. In the specimen

examined there was clear evidence of the previous existence of the conducting layer, *c*, and the three membranes were present, *i.e.*, the outer shell, a fibroid lining within that, and a third enclosing what I have termed the seed substance. In lieu of the tongue-like protuberance with which the chestnuts are provided a sharp point projecting inwardly from the base of the nut seemed to have served the same purpose, and at the apex was another point evidently open at one time to the air. In regard to colouring there was again in the white of the nut a faint tinge of lemon-yellow. I exposed one half to bright and the other to diffused light for four hours, when that in diffused light was apparently unchanged, while the other had taken on a tint of slightly deeper yellow.

THE ELECTRODES AND ELECTROLYSIS.

Where contacts of prolonged duration are made, as in the foregoing tests for capacity, suspicion naturally attaches to the electrodes, and it might be thought that the changes of polarity observed were due to polarisation. In this connection I would point out two things, *i.e.* (1) the needles were in some instances cleaned and reinserted without polarity being affected, and that in the orange test there were merely signs of electrolysis, and (2) that supposing 1.5 volts had in ten minutes polarised the electrodes inserted in the fruit or vegetable to such an extent that polarity was reversed for twenty minutes, it is difficult to see how an electromotive force of about 0.086 volt (*i.e.*, that of the vegetable cell) could restore the original polarity in another twenty minutes while the electrodes remained in position. Moreover, I have by repeated experiments, extending over a course of years, established the fact that it is impossible to alter the polarity of a vegetable cell by subjecting the

needles to electrolytic action possibly set up when they are left in such cells for several days at a time. Another thing of which sight should not be lost is the initial test of Turnip No. 2. The first charge of ten minutes with 1.5 volts was dissipated in less than ten minutes, but when the absolute insulation of the vegetable was improved in the manner described in the second and third tests it did not recover until thirty-four minutes had elapsed. The electrolytic action and consequent polarisation should have been the same in both tests, and altogether I think it must be agreed that the weight of evidence is in favour of capacity, and not polarisation of electrodes, as explaining the phenomena, although there can be no doubt that the electrodes were affected to some extent by electrolysis.

PRIMARY OR SECONDARY CELLS ?

The problem is, no doubt, possible of solution, but in so far as I am acquainted with the chemistry of the subject, I have yet to hear of a cell made by man in which there occurs no disintegration or no change, and which cannot be either polarised or discharged by continued short-circuiting.

Some vegetables and fruits, it is true, are more liable to decay than others, but decay interferes with their electrical activity only by diffusion, by breaking down the protection between the negative and positive elements, and, possibly, by setting up local action. Once that happens the process of decay is very rapid.

Their life—that is to say, their edibility as well as electrical activity—appears to depend largely if not to be in direct ratio to their absolute insulation resistance. Of all vegetables the onion has the highest and best absolute insulation, while among fruits the apple, the pear, and the quince, etc., are in the premier class. I have short-circuited onions through 0.1 ohm for many days at a time

without finding in them any evidence of polarisation or discharge, and as the E.M.F. of them all is the same—the current only varying in accordance with Ohm's law—the onion is, in my opinion, an ideal standard cell of low electromotive force for delicate galvanometric work. The apple and pear, offering as they do smaller contacts and more liability to diffusion at the points of contact, are not so generally useful, although, with care, they are reliable.

In regard to plants, shrubs, and trees, however, I have observed that during such time as they are 'resting,' as in the late autumn, winter, and early spring months, both electromotive force and current fall off, and this may be due to a deficiency in the quantity or flow of the sap, or both.

As regards the constancy of these cells I am inclined to think they must draw a positive charge from the air whenever their potential falls below that of the air, in the same way—as shown by the capacity tests—they give off to the air any excess of current with which they are artificially charged. No other explanation of their long-sustained electrical activity occurs to me, and if they are carefully examined it will be seen that the flower or foliage end of fruits and vegetables is not sealed so thoroughly and effectively as the stalk or root. If that is so they are storage cells in a new sense. In other words, they are maintained in a state of electrical activity by the air only, and it would not be possible, by joining them up in series, to increase their electromotive force beyond that of the air, because if it could be augmented—and I do not believe it can—by such an arrangement, any excess of potential above that of the air would be given off instantaneously. We have seen that an artificial charge is retained for some little time, but that, inevitably, the vegetable cell reverts to its normal electromotive force and polarity.

WATER IN ITS RELATION TO PLANT LIFE.

If, as it would appear, a constant supply of electricity from the *earth* is necessary to the well-being of everything that grows therein, the fact that *dry* soil is a bad conductor of electricity assumes an important aspect. In the experiment about to be described a quantity of earth was dug from the garden, carefully sifted and weighed, and equal quantities were placed in three porcelain pans of equal dimensions. These were labelled 1, 2, and 3. Nos. 1 and 2 were put in a gas oven and baked, the soil being frequently turned over, until all moisture was expelled. No. 1 was then protected from moisture, and after a solution of one per cent. of ferro-sulphate had been mixed with the soil in No. 2 it was again baked until it had become dry; No. 3 was left untouched.

A galvanometric test of pan No. 1 gave no deflection whatever, whilst Nos. 2 and 3 (No. 2 being dry) exhibited no difference in their electrical conductivity; pointing to the fact that, considered as an electrolyte, ferro-sulphate was an efficient substitute for water. The next step was to sow exactly the same weight of mustard seed in each of the three pans, which were then placed in a room in a diffused light with free access to the air.

No. 1.—Baked dry earth.

No. 2.—Baked dry earth containing ferro-sulphate,
and

No. 3.—Moist earth as taken from the garden.

No. 3 was watered in the usual manner—that is to say, care was taken to keep the soil thoroughly moist—but Nos. 1 and 2 were given only ten per cent., in the form of spray, of the quantity of water accorded to No. 3.

The outcome of the experiment was that while the seed in No. 1 did not germinate, the growth in Nos. 2 and 3 exhibited no apparent difference.

Had the experiment been carried out in a frame, so that the soil could have received its charge from the negative earth instead of from the positive air, the results obtained would not have been so conclusive, as percolation of moisture from below could not have been guarded against. As it was, one could reasonably infer that the small percentage of conductive mineral in the soil of No. 2 acted, in conjunction with the water, as an electrolyte, and so relieved the latter of part of its duties. I say in conjunction with the water, because without moisture there can be no conductive or inductive capacity in soil or in plant life.

It would be interesting to learn whether in countries subject to drought comparison has been made, under similar climatic conditions, between districts where the soil is and is not ferruginous. In Egypt the sand generally contains some mineral salts, and a minimum of irrigation is, more often than not, generously responded to. The question is one of some importance, more especially in relation to the Indian famine problem: the rice plant requiring an excessive amount of water for its successful cultivation.

THE EFFECT OF ELECTRICAL STIMULATION UPON GROWTH.

In *A Text-book of Biology*, by J. R. Ainsworth Davis, B.A., it is said: "Electricity probably plays an important part in growth, as electric currents taking various courses have been demonstrated in living plants. *Currents artificially sent through a root have been found to retard its growth.*"

The sentence in italics, taken without qualification, is I think, incorrect. It depends, in my judgment, upon the sign of current and the electromotive force employed. A current of positive sign applied to the root of a plant growing in the earth might exert a retarding influence, and, similarly, one of negative sign to the soil of a pot plant.

But given proper connections and an electromotive force not greatly in excess of that of the earth or air, the effect of electrical stimulus should be beneficial.

This opinion is not merely theoretical, but a result of long-continued experiment.

Years ago I boiled one potato and baked another for fifteen minutes and allowed them to get cold. Precisely what had taken place I do not know, but they gave no reversal of sign, and except that, by reason of the water in them, they still possessed capacity were, so to speak, electrically dead. They were then each joined up by steel needles to a dry cell (zinc to unprolific and carbon to prolific eye) and left for twenty-four hours, when they were disconnected. Thereafter they not only gave perfect reversals, but began to sprout in a quite remarkable manner.

Another test was with tomato plants in the greenhouse. Hypothetically a plant grown in a pot is grown under unnatural conditions, because it is cut off from the negative earth-current and compelled to take its root-charge from the positive air.

I therefore planted twelve tomato plants of exactly the same size and description in pots of equal size and with uniform soil. Six of them were treated in the usual manner, but the other six were connected directly with the earth by means of stiff copper wires from the soil in each pot to the earth beneath the slats upon which the pots rested; all the plants being given the same amount of water.

In the end the last-named six were infinitely more robust and bore heavier crops than the others.

A third experiment was with two onions, neither of which exhibited any outward sign of growth. Each of these was connected to a dry cell (1 volt), but with reversed connections; the object being to ascertain what effect, if any, the polarity of the stimulus had upon growth.

The two vegetables in question are shown in Figs. 20 and 21. Steel darning-needles were again used, and by means of these the zinc of one dry cell was connected with the root and the carbon with the foliage end of A (Fig. 20), while in the case of B (Fig. 21) the arrangement was carbon to root and zinc to foliage end. Both were then left in a room in a weak diffused light for five days and then sketched.

The drawings are explanatory in themselves, but it is worthy of remark that A gave evidence of growth within twenty-four hours under what may be termed natural stimulus, while, though it cannot be positively asserted that in B there was a retarding influence, it appeared that growth was not stimulated. This, in a measure at all events, proves my point that the value of electrical stimulus is largely dependent upon sign of current, and lends colour to the suggestion that the employment of low electromotive forces in agriculture and floriculture is in harmony with natural laws.

CHAPTER III

THE EMPLOYMENT OF ELECTRICITY IN
AGRICULTURE

It is now more than a hundred and fifty years ago that a Scotsman named Mainbray attempted to stimulate growth by electrifying the soil, and since then experiments on a large scale have been and are being carried out at Helsingfors, Brodtörp, Breslau, the Durham College of Science at Newcastle-on-Tyne, and elsewhere ; the method employed being high-tension electricity, usually generated, I believe, by a Winshurst machine or machines, and carried by a network of bare wires strung upon insulators affixed to poles some six feet or so in height, and covering the field in which the vegetables are grown.

The results have occasionally, it may be frequently, been satisfactory, but I cannot help thinking that, as a matter of possibility, they may have been due to the formation of nitrous oxides at the sparking points, and that better results may be obtained by studying Nature's methods and endeavouring in a more modest and inexpensive way to improve upon them.

I am reminded, in fact, of high-frequency treatment of the human body. It does not rest upon any definitely ascertained scientific basis, and might be relegated to the scrap-heap without injury to mankind.

While my observations upon this subject are speculative, in that no experiment upon a sufficient scale has yet been made with low-tension continuous currents, we have

some evidence of their effect upon the onion when the negative pole is applied to the root and the positive pole to the foliage, and it should be worth while to experiment with, say, five or ten volts similarly applied to a field of several acres.

Another point which should not be lost sight of is that some plants suffer from *chlorosis*, the disease being due to deficiency of iron.

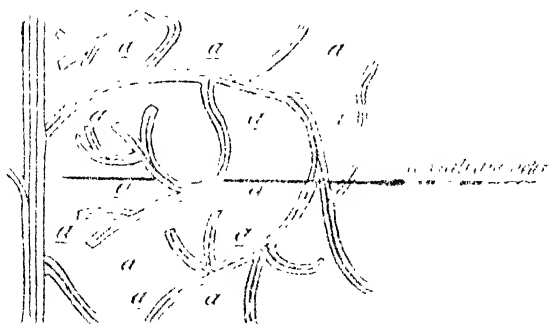
Now, while it is true that the atmosphere is positive and the earth negative, it also seems that Nature seldom if ever relies entirely upon the constant and unintermittent maintenance of any single condition upon which life depends, and it is quite possible, even probable, that electrical generation goes on in the plant itself. Most, if not all, plants contain iron, and all of them inspire oxygen; two elements which, in the presence of a suitable alkali—and this we know to be contained in the protoplasm—are capable of generating electricity. During periods of drought the root-supply of current may, conceivably, be cut off by non-conducting dry earth, and if that current is necessary to the plant it would perish had it not any other source of supply: whereas so long as its protoplasm remained in a fluid condition it would, with some measure of independent generation, be better fitted to endure hardship. Take, for example, the savoy cabbage. The outer green leaves contain a comparatively large quantity of iron (17 milligrams per 100 grams of substance), and those leaves—standing out from the closely-folded heart of the plant—would have the largest oxygen intake. It would not be necessary for that process to extend throughout the plant, because it could be continued from the outer leaves by conduction and induction if for any time during the twenty-four hours even the surface of the soil was moistened, as by dew.

According to Sachs, *chlorosis* in plants may be cured by

mixing a small quantity of ferrous sulphate, in solution, with the soil ; but even where the disease does not exist iron should, in my opinion, be used as an electrolyte and the result noted.

NOTE FOR GUIDANCE IN TESTING.

For everything that grows, either in the earth or in a pot, it is only necessary to have flexible wires of low resistance and of a sufficient length to span the space between the galvanometer and the plant. Both wires should terminate in two darning-needles of equal gauge and length. One needle may be inserted in the open ground or in the soil in the pot, and the other carefully placed in between the lignified fibres in the venation of a leaf, *i.e.*, in the interspaces, or areolæ, which are filled up with transpiratory assimilating tissue. Contact with the venation may introduce error, but if ordinary care is taken there will not be any discordant result. The needles must, of course, be kept scrupulously clean, and should not be insulated for any portion of their length, as such insulation



a, a, a are the areolæ. The needle should be inserted as shown.

—whether by india-rubber or gutta-percha, etc.—is liable to cause confusion. Plain, clean needles, well-insulated

wires, and clean ends to them will save much trouble. If the connecting wires are of sufficiently low resistance it does not matter whether the object to be tested is one yard or one hundred yards from the galvanometer.

In order to make my meaning quite clear I have given a sketch of a part of a leaf of *Anthyllis Vulneraria*. The enclosed interspaces, or some of them, are those which should be connected up, while the dark parts are those which should be avoided.

Part II
STUDIES IN ELECTRO-PHYSIOLOGY :
ANIMAL AND VEGETABLE

CHAPTER IV

REVIEW OF ELECTRO-PHYSIOLOGICAL RESEARCH

Put briefly, the history of electro-physiological research is one of contradiction, confusion, and uncertainty. To this day the medical profession regard with a not unmerited degree of suspicion the results and theories of those very able men who have for the last hundred and thirty years or so laboured in this field of scientific investigation. Had it not been for their failure to discover certain facts of primary importance, facts which would have made all things clear to them, electro-physiology would long ago have enlightened and led the world of medicine.

Later on I will give those facts the prominence they deserve, but before doing so it may be useful to offer a short recapitulation of what has been done.

From *A Practical Treatise on the Medical and Surgical Uses of Electricity*, by G. M. Beard, M.D., and A. D. Rockwell, M.D., I quote the following :—

“Those who aspire to mastership in electro-therapeutics will not be content with the mere attempt to relieve symptoms; they will seek to study those most complex and subtle diseases for the treatment of which electricity is indicated; *they will resort to this force for diagnostic as well as therapeutic aid*; they will strive to know not only how to use it, but, what is more difficult, *how not to use it*. He only can reap the full and rich harvest of electro-therapeutical science and art *who sows beside all waters*;

he must become more or less proficient in neurology, in electro-physics, and in electro-physiology. *He who has a knowledge of the laws of animal electricity*, and the actions and reactions of franklinic, galvanic, and faradic electricity on the brain, spinal cord, and sympathetic; on the nerves of motion and of common and special sense; on voluntary and involuntary muscles; on the skin, and on all the various passages and organs of the body in health, and also of the electro-conductivity of the body, will find the paths of electro-diagnosis and of electro-therapeutics illumined at every step by such knowledge, and will, in the end, make more correct interpretations of disease than he who merely holds electrodes on patients without any higher aim; and more than that, he will be introduced into a field of thought and experiment—a field surpassingly rich and fruitful—and lying in close relation to all departments of physiology, of pathology, and of biology, where he can study science for its own sake.”*

To go back to history, it was in 1786 that Galvani discovered that muscular contraction followed the contact of the nerves and muscles of a frog with a heterogeneous metallic arc. He theorised, and his theory was that in the tissues of animals there existed a special independent electricity, which he called *animal electricity*. Later observers admitted the existence of animal electricity as a force, but explained it by contact of dissimilar substances and by the chemical action of the fluids of the body on the metals. This erroneous and untenable theory is upheld by the average physiologist of to-day.

Volta's researches followed, and in 1799 Humboldt published a work which went to show that Galvani and Volta were both right and both wrong; that there *was* such a thing as animal electricity; that Galvani was in error in

* The italics are mine.

regarding it as the only form of electricity that appeared in his experiments; and that Volta was wrong in refusing to admit its existence.

In 1803 a nephew of Galvani, Aldini, published experiments that went to demonstrate the existence of animal electricity. The voltaic pile, however, was a stronger argument against the existence of animal electricity than any experiments could be in its favour, and for these reasons animal electricity was forgotten.

The electromotive force of a voltaic pile would be, approximately, 1 volt per cell, while that of the human body is, also approximately, 0.004 volt in its entirety. It is difficult to see how Aldini arrived at his conclusion.

In 1827 M. Nobili, having constructed a very sensitive galvanometer, claimed to have detected the existence of an electric current in the frog; a few years subsequently Matteucci had turned his attention to this subject, but it was reserved for Du Bois-Reymond to investigate most clearly and most fully, if not most conclusively, the electric properties of the nerves and muscles.

By these two observers (Matteucci and Du Bois-Reymond) it was believed to have been shown—

1st.—That currents in every respect like the frog-current of Nobili were not peculiar to the frog, but were inherent in all animals, warm and cold-blooded—in toads, salamanders, fresh-water crabs, adders, lizards, glow-worms, and tortoises, as well as rabbits, guinea-pigs, mice, pigeons, and sparrows.

2nd.—That currents are found in nerves as well as muscles, and that both are subject to the same laws.

3rd.—That this muscular current may be upward or downward, and that the current of the whole limb is the resultant of the partial currents of each muscle.

4th.—That electricity is found not only in the muscles and nerves, but also in the brain, spinal cord, and

sympathetic; in motor, sensory, and mixed nerves; in a minute section, as well as in a large mass, of nervous substances; in a small fibril as well as in a large muscle; in the skin, spleen, testicles, kidneys, liver, lungs, and tendons; but not in fasciæ, sheaths of nerves, and sinews.

It is over one hundred years since Du Bois-Reymond taught us this, and we have learned nothing from it.

The next prominent exponent of electro-physiology was Dr. C. B. Radcliffe, who sought to prove that the sheaths of fibres of nerve and muscle *during rest* are charged with electricity like Leyden jars. He postulated the theory that the sheaths of the fibres were dielectric, but did not attempt to differentiate the "open" from the "closed" circuits of the nervous system.

He said: "When a nerve or muscle passes from action to rest it resumes its condition of charge." But "elongation, therefore, is the result of charge, and contraction of discharge."

This view is, of course, quite fallacious. The reverse obtains. When an impulse is conveyed to certain groups of sarcomeres they contract; when discharge takes place they elongate, and are again in readiness for charge.

Then we had Professor John Trowbridge, of Harvard College, who cast grave doubts upon the interesting and hitherto accepted conclusions of Du Bois-Reymond in regard to animal electricity, and ascribed the whole phenomena as due to the alleged fact that two liquids of dissimilar chemical character, separated by a porous partition, gave rise to a current of electricity. More recently this somewhat far-fetched hypothesis of dissimilar fluids has been substituted by two dissimilar metals; *i.e.*, electrodes; the theory being that electrical action is set up between two electrically dissimilar metals—the electrodes—in the presence of an exciting liquid, such as the secretion of the sweat-glands.

This, I think, brings us more or less up to date, and leaves the so-called science of electro-physiology in a somewhat hopeless condition. No two sets of observers are in agreement, and, as a matter of fact, the general medical practitioner has in his heart about as much respect for electro-physiology as he has for manifestations of the occult.

All this appears to be very extraordinary and difficult of explanation. How is it that these great men of science were not only unable to agree but really discovered very little of service to humanity? The reasons are not far to seek.

In the first place they were not, any of them, trained submarine-cable electricians, specialists in their work, whose business it is to acquaint themselves with the conditions under which tests of such extreme delicacy and difficulty must be conducted. For this branch of research a specialist electrician is imperatively called for.

The causes of the confusion, the sources of error in the past, lie, in the main, in three factors which have never been taken into consideration, for the reason that they were not discovered. These three factors are—

- (1) The constant electro-chemical generation of nerve-force in the human body.
- (2) The presence in that body of great conductive and inductive capacity; and
- (3) The conductive and inductive capacity of every liquid and every moist substance or object.

Let us see how these factors come into play as sources of error.

That the human body generates static electricity—by muscular movement—is well known, but this charge can be dissipated in a few moments by placing the body—preferably by the palms of the hands—in contact with an earth plate of low resistance. That it possesses electro-

static capacity is also known, because when perfectly insulated the body can be charged to a high potential. That it has inductive capacity also is not so well understood.

So far as capacity is concerned, we may liken the body to a collection of storage cells or Leyden jars, which are liable to become more or less highly charged, or to have their charge altered by any direct or passing current or exciting influence, or change in exterior insulation.

Now, these storage cells or Leyden jars cannot, if they depend for their charge upon some outside source of energy as the exciting influence, be in a constant state of tension, because the outside current is not always flowing either to charge them directly or by passing in their vicinity. We must then depend upon muscular movement for the charge, and if we find, as we do find, that movement of any kind exercises only a momentary effect upon the human electromotive force, and that, within limits, such electromotive force continues to be produced even when the body is absolutely motionless, we must look further for the source of energy.

CAUSES WHICH HAVE CONTRIBUTED TO ERROR.

We will now take the three factors I have mentioned *seriatim*, but before doing so it would be well to mention that in the majority of tests, upon which the conclusions to be given hereafter are based, a Kelvin Astatic reflecting galvanometer of a resistance of 88,000 B.O.T. ohms at 15° C. and perfect insulation was used. This instrument was made for me by Elliott Bros., of Lewisham, and its sensibility was such that a scale deflection of 400 mm. from a central zero could be obtained with a current of 0.1 micro-ampere. (See p. 235.)

The electrodes I will describe later.

Now, it is quite clear that if nerve-force, or, as I prefer to call it, neuro-electricity, is constantly generated in the body, it must be as constantly given off, otherwise the neuro-electrical pressure would become excessive. The absolute insulation of the body is provided by the skin, but the skin is not an insulator of very high resistance. Nor is its resistance uniform, any more than the generation of neuro-electricity is uniform in all individuals. *Sign, electromotive force, and current* vary with the person as much as height, weight, and anthropometric measurements vary.

If nerve-energy were visible we should probably see every human being—one might say every living thing—surrounded by an aura, or neuro-electrical field, extending some distance from the body and gradually fading into space.

We must, however, realise that the rapidity with which that neuro-electricity can pass to earth must depend upon the manner in which the body is protected or insulated from the earth by dielectrics other than the skin. For example, the insulation of a carpeted room with the windows and doors closed would be infinitely higher than if the body were exposed to the open air, or in contact with damp earth, or with the hands touching some metallic substance connecting with the earth. We may, in fact, conceive many conditions in which the insulation of the body could be increased or impaired.

In considering "air" as the normal "earth" of the body it must not be thought that I am unsupported in the view I have taken, although physicists may not, so far, have fully appreciated the conductivity of air, under varying conditions of humidity and movement, in its relation to that form of energy called nerve-force, or even to electricity of so low a tension as 4 or 5 millivolts.

In his *Physiological Physics* M-Gregor-Robertson, who will be remembered in connection with the University of Glasgow, says: "A charged body in a current of air slowly

loses its electricity by convection. Particles of the air coming in contact with the body receive a charge, and pass on, to be succeeded by other particles, each of which carries off its portion, till the whole charge is thus dissipated."

Dissipation by convection does not *fully* explain the phenomenon. Hot air, inferentially, is dry air, and dry air is a bad conductor. All the neuro-electricity given off in a room does not, therefore, form a stratum near the ceiling, and a "current of air" may be variously construed. Anyone moving about in the testing-room, draught from the door, window, or floor, or even the breath of the persons present may create such a current. In any case, however, the air is an "earth" of high resistance, and the higher its resistance—dimensions being equal—the quicker the atmosphere of the testing-room will become charged with neuro-electricity, because of the increased difficulty placed in its path to a true "earth."

That being so, it is evident that while the generation of neuro-electricity in the body might be deemed to be constant, the dissipation of it cannot be so by reason of the varying conditions of exterior conductivity.

Another important point to remember is that the sign of current in individuals is not always the same. The palms of the hands, being free from sebaceous glands, are the most convenient body terminals, but, until determined by test, the body resembles a galvanic cell whose terminals, electromotive force, and internal resistance are unknown.

The bearing of all this upon error will soon become apparent. Let us imagine ourselves in a laboratory, the floor and walls of which oppose considerable resistance to the escape of electricity, and let there be two people reproducing, say, the experiments of Professor Trowbridge. We, however, will take the precaution of testing them for personal neuro-electricities, and, to quote figures obtained in actual practice, say that A gave a deflection

of 2000 mm. positive and B of 40 mm. negative upon the scale of the galvanometer I have mentioned. After about an hour, or less (according to the size of the room), the air of the laboratory would become charged by reason of the neuro-electricity emanating from the persons of A and B, and as 200 positive minus 400 negative = 200 negative, the air must become negatively charged, increasing in tension or pressure with time or varying with any alteration in the insulation.

In this we have one of the sources of error. The tension and sign of the atmosphere in the testing-room have always been unknown quantities.

PERSONAL CAPACITY

I have not of recent years taken any actual measurements, but the mean of a former series of tests gave nearly four microfarads as the average capacity of the body. Now if B (= 400 mm. negative) touched A (= 200 mm. positive), A would become 200 mm. negative so long as he remained shut up with B, or, failing direct contact between the two, the air of the room would charge A as certainly as water would find its level. Inductive capacity introduces another and equally perplexing source of confusion, as a flash of lightning, a powerful earth-current, wireless telegraphy, or the proximity of a charging station or of an electric railway or tube would not only affect the persons experimenting, but also the subject of experiment, although a galvanometer of the d'Arsonval type might not be perceptibly influenced.

CAPACITY OF LIQUIDS AND MOIST SUBSTANCES

But that is not all. Physiologists, overlooking conductive and inductive capacity, have invariably used what they call non-polarisable electrodes, or contacts to which the objects under examination are connected, for the purpose of

conveying the currents of electricity supposedly emanating from them to the coils of the recording instrument. These electrodes were, and are, moistened with some liquid, and as all moist substances absorb electricity as a sponge absorbs water to the limit of its capacity, it follows that unless each electrode is of exactly the same area and density, there will be a controlling current from one of the two. It also follows that if one electrode has a thousandth part more moisture than the other, an opposing electromotive force, so to speak, may be exerted by it, and furthermore, disregarding minor details, those electromotive forces would be liable to variation from time to time by—

- (1) The number of persons present in the laboratory ; the length of time they remained there, and their respective neuro-electrical signs and electromotive forces.
- (2) The nature of the liquid or liquids employed.
- (3) The degree of absorption.
- (4) The area of the electrodes ; and
- (5) The amount of moisture present in the object or subject under examination.

Let us suppose A and B to have been experimenting with a piece of excised muscle in a moist condition and to have obtained certain data. Their results would always check, because the muscle would invariably have a charge equal to 200 mm. negative.

Two other persons, C and D, question the accuracy of the published results of A and B, and proceed to verify or disprove them. C, let us say, = 300 mm. positive and D 150 mm. negative. The resultant charge would, of course, be representative of 150 mm. positive, the muscle would be differently electrified, and the data obtained could not agree with the results of A and B. In the same manner E and F may prove both A and B and C and D to have

been hopelessly incompetent, and in their turn be subjected to similar criticisms at the hands of others.

As a great deal which does not happen to be true has been written about non-polarisable electrodes, it may be well at this juncture to give an account of a few experiments which were carried out with the object of exploding some cherished theories.

I found that when two wires of equal gauge and length, soldered to two steel needles of exactly the same gauge and length, were connected to the terminals of the galvanometer, and the needles were inserted in various objects and liquids, certain deflections were observed—deflections which were not momentary, but more or less constant.

These deflections are explained as being due to galvanic action.

There are two theories, *i.e.*—

- (1) Two metals—that is to say, one electrode being electrically positive to the other—in one solution, or
- (2) One metal in two solutions.

It will, however, be only necessary to consider the first seriously, inasmuch as there cannot be two different fluids in distilled water, while the most careful analysis has failed to reveal the presence of two widely differing solutions in the juices of fruits and vegetables. Nor can the first hypothesis be sustained, if only for the reason that the sign of the deflection obtained is not altered by the reversal of the needles upon the terminals of the galvanometer.

In the case of liquids such as distilled water, and all lifeless moist objects, the deflections given by them must be of the same sign, and that sign is, and must be, governed by the sign of the electricity or neuro-electricity with which the air of the testing-room is, for the time being, charged; that is to say, when the two wires and electrodes are of the same metal and of equal resistance, the deflections which

occur are always ascribable to charge imparted by some source or vehicle of energy to the article under examination.

As I have before remarked, it is owing to this fact, and to the further important truth that all fluids and moist objects possess conductive and inductive capacity, that the results obtained by various investigators have so materially conflicted.

But when under the same conditions we test anything in which there is life, we have different factors to deal with. In the section upon Electrical Structure and Function in Plant Life I have given a summary of some ten thousand tests of fruits and vegetables in which I used steel darning-needles as the electrodes, but one or two of them may be repeated here.

First theory: Take two equal lengths of insulated flexible copper wire and solder to each length a steel darning-needle, connecting the other ends to the terminals of the recording instrument. Call the needles R and L respectively.

Now select a sound onion and insert the R needle in the root, and the L needle in the foliage end. Upon depressing the galvanometer short-circuit key a constant *negative* deflection will be observed. Theoretically, therefore, the L needle is electrically positive to the R needle, and the juice of the onion being the exciting liquid galvanic action is set up. If that is so, and if we do not reverse the connections, the polarity of the needles is established, and we must continue to get a negative deflection, no matter where we insert the needles. If, however, the onion is reversed, so that the R needle is in the foliage end and the L needle in the root, there will be an equally constant *positive* deflection, showing that the difference in polarity is in the vegetable, and not in the needles.

Again, take two suitable electrodes, say two silver rods 6 in. by $\frac{3}{4}$ in., provided with terminals; attach them to

two equal lengths of wire and connect as before. Hold the R electrode in the right and the L electrode in the left hand, being careful that the pressure is equal. The sign of the deflection is, we will say, positive. It follows, therefore, that the R electrode is electrically positive to the other. Leave the connections unaltered, but hold the R electrode in the left and the L electrode in the right hand. If the polarity is in the electrodes the sign of current will be the same. But it is not. The deflection will be negative, because polarity is in the hands and not in the electrodes.

In this connection proof can be multiplied almost *ad infinitum*, but I do not wish the case to rest upon my unsupported testimony.

In an article in the *Lancet* of January 13, 1917, Dr. C. Nepean Longridge, F.R.C.S. Eng., M.R.C.P. Lond., who has been examining and treating various cases on my principles for some two years, says—

“ *Experiment 1.*—With the aid of Miss Flecker, at the Ladies’ College Physical Laboratory, Cheltenham, I estimated the electrical resistance of a piece of oak-tanned sole leather 3 in. long by 1 in. wide. We found that when dry the resistance was practically infinity. When wet the resistance is that of the fluid the leather has soaked in.

“ *Experiment 2.*—One pole of the galvanometer was connected to an electrode which could be held in the hand. The other pole was connected by an insulated cable to a copper plate imbedded in the earth. Another insulated cable was connected at one end to the metal pipe supplying water to the house, and at the other end to a brass rod of 1 in. section. After earthing myself I held the brass rod in one hand and the electrode in the other, and obtained a rapid off-scale deflection, showing, firstly, that an electric current was coming from my body ; and secondly, that the earth connexions were working properly, for the current passed out by one hand through the brass tube to the

water-pipe, thence about 20 ft. through the earth to the copper plate, and through the galvanometer to the other hand, so completing the circuit.

“ *Experiment 3.*—The brass tube was then laid on the floor, which was covered by a thick carpet. I held the electrode by one hand and put both feet on the brass tube. I wore ordinary boots, which were dry. No deflection was obtained, because the dry leather soles of my boots insulated me from the earth. I then took my boots off and put my bare feet on the tube and obtained an off-scale deflection.

“ *Experiment 4.*—Next day was wet, and I walked about half a mile, so that the soles of my boots, which were free from holes and metal nails, became wet. On holding the electrode in one hand and placing my feet on the brass tube a rapid off-scale deflection occurred, showing that current was passing through my boots to earth.

“ *Experiment 5.*—The pole of the galvanometer connected to earth by the copper plate was disconnected. It was reconnected to a hand electrode exactly like the one previously used, so that the galvanometer was now connected to the hand electrodes only. After the necessary earthing process, I held the electrodes in the hands and obtained a deflection which remained steady at 170 mm. I then placed my feet, still in wet boots, on the brass tube and awaited results. The light on the scale very slowly began to recede towards zero. I repeated this experiment several times. The light never remained at zero, but if it got as far went over to the other side of the scale, and generally registered 40 to 60 mm. I take this as evidence that electricity was gradually leaking out of my body to earth, through my wet feet. One would not expect the light to register zero, as there is a continuous generation of electricity in the body. In view of these experiments, the grandmotherly advice we have so often received, not

to stand about in wet boots, takes on a new and important significance which ought to claim our belated respect. They also, to my mind, afford evidence that trench foot is probably caused by long-continued leakage of electricity from the feet."

In regard to experiment 2 it may be urged by the supporters of the difference in metals theory that it does not present any new feature, while the fact of there being no deflection in experiment 3 can be explained by the absence of moisture at one pole, and therefore of the improbability of galvanic action taking place. Experiments 4 and 5, however, are, to my mind, quite at variance with that theory, and appear to negative the conclusions of those who have been and are responsible for it.

In my work upon *Electro-Pathology and Therapeutics* I stated that the thumb of each hand was of opposite sign to the fingers of each hand and carried a greater quantity of current.

Dr. E. W. Martin, who has had some few years' experience of my methods, has sent me the results of a series of tests carried out by him, and gives his conclusions as follows:—

"It would therefore appear that—

- “(a) There is no electrical current generated by two metals in contact, even in the presence of moisture.
- “(b) A current passes when *both* hands are in contact with both electrodes.
- “(c) That different conducting substances act differently in their relation to the body current.
- “(d) That the current *cannot* be due to the moist skin and metal only, as we find that in a complete circuit from skin and metal to skin and metal no current is set up so long as one hand only is used.
- “(e) That the thumbs appear to be electrically as well as anatomically in opposition to the fingers of the

same hand, and equally in opposition to each other, and that they appear to form terminals of a circuit with the fingers of the same hand, as when the thumb is brought into contact a current at once passes.

- “(f) That the approach of the thumb to the electrode, even without contact, produces a slight deflection which is probably not static, as the deflection remains after all movement, so far as it can be controlled, has ceased.”

The main points touched upon by Dr. Martin, *i.e.*—

- (1) That unless both hands are used the contact of skin and metal will not exhibit electrical action, and
- (2) That the thumbs are of different sign to the fingers—

may be very simply and conclusively proved in the following manner :—

Take two electrodes, of the same size, of copper, silver, or German silver, and connect them by two wires of equal gauge and length to the terminals of the galvanometer. Insert one of these electrodes between the first and second and the other between the third and fourth fingers of the left hand, and do not allow them to touch. *No deflection will be observed* unless the hand is wet. In that case there may be a slight leakage from the thumb. Then bring the left thumb into contact with one of the electrodes and a deflection will at once ensue. Repeat the experiment with the right hand and the result will be the same, only that the deflection ultimately obtained will be of opposite sign.

This experiment as conducted by Dr. Martin is thus described by him—

- “(a) One electrode was placed between the third and fourth fingers, the other electrode between the first and second fingers of the left hand; not allowed to touch each other. Key closed, *i.e.*,

Circuit from skin and metal, through galvanometer, to skin and metal. Deflection, nil.

“(b) Repeated with right hand. Deflection, nil.

“(c) Terminals allowed to touch. Deflection, nil.

“(d) Same position electrodes, left hand. Thumb approximated to electrodes. Deflection, slight. Thumb touching negative pole electrode. Deflection, negative. Thumb touching positive pole electrode. Deflection, positive.

“(e) Same experiment repeated with right hand and right thumb gave a reverse result, *i.e.*,

+ pole == deflection negative
— pole == deflection positive.”

In order to reconcile these results with the views of physiologists we should have to assume—

- (1) There are no sweat-glands in or moisture upon the fingers of either hand, and
- (2) That the thumbs only contain sweat-glands or exhibit moisture, and that their secretion or the moisture is of so opposite a character, chemically, as to instantly change the polarity of the electrodes touched by them.

No comparison is possible between the currents set up by a galvanic cell and those emanating from the human body. The former is a simple generator of electricity; the latter a complex system from which electricity or neuro-electricity is constantly being given off. It is only necessary to establish a difference of potential at two points in one or more bodies to obtain deflections, due to direct or derived circuits. Owing to the absence of sebaceous glands in them, the palms of the hands and soles of the feet are, no doubt, the natural “earths” of the body, but nerve-energy must escape, to a greater or lesser extent, from every square inch of the skin.

Again, examine, galvanometrically, by means of the hand-to-hand deflection, a number of persons until three

are found who yield a positive and three a negative reaction. If the observer himself is of positive sign two other positives only will be required, and *vice versa*. Then let the testing-room be vacated for several hours and freely ventilated.

As a next step introduce each of the persons selected to the testing-room, one by one, "earth" the subject for five minutes, and take the hand-to-hand deflection very carefully, noting the sign and number of millimetres and ushering the subject from the room before the next one is admitted.

Let us assume that the deflections are respectively as follows :—

Observer	=	250	mm.	positive
First subject	=	200	„	„
Second „	=	225	„	„
Third „	=	250	„	negative
Fourth „	=	200	„	„
Fifth „	=	225	„	„

These figures might not actually obtain in practice, but they will serve to illustrate my meaning and are sufficiently near to the truth.

Having registered the above data. let the observer and the five subjects assemble in the testing-room and remain together for a few hours, the length of time being dependent upon the size of the room and its insulation from the earth. If it is of moderate dimensions, carpeted, and with doors and windows closed, two hours should be sufficient. Then, without earthing and without anyone leaving the laboratory, take the hand-to-hand deflections again, in the same order.

Now, if the differences in polarity and in the number of millimetres exhibited by the subjects are due to dissimilarity of metals, acted upon by different secretions of the sweat-glands, the deflections should be as before,

though there might be variations of a few millimetres due to increased or decreased moisture or pressure of one or other of the hands. If, however, my contention be correct that we give off neuro-electricity to the air in accordance with our respective sign and electromotive force, and that the body is liable to be inductively influenced, it is obvious that a common level would, in time, be found, and that the resultant hand-to-hand deflection of each and every one of the persons present must be in the neighbourhood of zero.

That is what actually happens.

I read somewhere, but regret the source is not given in my notes, that we may consider as generators of energy a liquid passing from a higher to a lower level ; heat passing from a hot to a cold body ; electricity flowing from a body with a high potential to one with a low potential ; movement transmitted from a body animated by velocity to another with less velocity, etc. Thus energy depends on the state of the bodies in presence. There is only an exchange between them if they are out of equilibrium ; that is to say, if they possess different tensions. One of the bodies present then loses something which it yields to the other until their tensions are equalised.

We are well aware that when two pieces of the same metal are placed in a solution in a circuit in which a current of electricity is flowing electrolytic action will be set up. Polarisation is the inevitable consequence of any such combination. But when we are calculating forces it behoves us to take into consideration the difference between a steam-hammer and a tack-hammer ; to discriminate between a hurricane and a zephyr. In a single dry cell a force of 1,500 millivolts is evolved ; the human machine is driven by 5. Moreover, the electrodes used by me for body-testing are of German silver, heavily coated with chemically pure silver, and as they are all

electro-plated at the same time in the same vat and with the same metal, the possibility of any dissimilarity is reduced to a minimum. Furthermore, contact with the body is not made for a sufficient time for polarisation to occur. In addition to that the conditions are not identical. In a galvanic cell or battery there are only two terminals, positive and negative. In the human hands there are four terminals—a positive and negative to each hand—and this would again tend to check polarisation, even with inferior electrodes.

With these observations it may safely be left to the impartial reader to hold the scales between physiologist and physicist. I have laboured the point at length because it lies at the root of the whole matter. This, as I believe, untenable theory of two, alleged, dissimilar metals in the presence of moisture has not only hampered progress during the past century, but is even now being put forward to bar our way to enlightenment.

The second theory—that of one metal in two dissimilar solutions—is, I venture to think, sufficiently disposed of by the electrical response of earth-grown and pot-grown plants and fruits, and calls for no further remark.

Suggestion.—In much the same way that the average cable electrician has been accustomed to attribute certain galvanometric deflections to “leakage,” some physiologists seek to find in “suggestion” an explanation of many of the proofs of successful treatment which have been brought forward. In taking cardiograms by means of the string galvanometer psychological influences cannot be disregarded, because the heart can be psychologically influenced through the cardiac branches of the vagi, but, by my method of testing, the deflections registered by galvanometers of the Kelvin or d’Arsonval type are only subject to variation by differences of pressure upon the

electrodes, which by bringing conductors nearer to the surface of the skin lower the skin resistance.

Hand-to-Hand Deflection and Thumb Pressure.—The importance of the hand-to-hand deflection, as being the measure of the electromotive force exerted in the body at the time of testing, is fully treated in the chapter upon Ohm's law and electro-diagnosis, but it may serve a useful purpose to explain what happens when there is inequality of pressure of the two thumbs. The body is connected in the galvanometer circuit by means of two suitable metallic electrodes, grasped in the hands, and a certain deflection is obtained. The thumbs carry a greater quantity of current than the fingers, so that if one is pressed harder than the other the deflection is altered, while if one thumb is relaxed and the other pressed down there may even be a reversal of sign, because the direction of current is determined by the path of least resistance.

Even some electricians of my acquaintance find this difficult to understand. They are accustomed to reason in terms of bare wires, and forget that the wires or conductors of the thumbs have an outer coating, or absolute insulation, of 5,000 or more ohms resistance, in the skin. Suppose this resistance to remain unimpaired upon one thumb and even partly removed from the other, and the path of least resistance becomes obvious. If, however, polarity was in the electrodes and not in the hands, no reversal of sign could be brought about by such difference of pressure.

A simple diagram will explain the differences of thumb pressure.

Let the body be represented by a source or sources of electrical energy, the arms by two coils of equal resistance, and the thumbs by two variable resistance-boxes, *a* and *b*. The quantity of current arriving at points *c* and *d* will be exactly equal, because, finding two paths of the same

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resistance, the current will divide at the battery terminal, and if a and b are exactly balanced (no matter what their resistance) no current will pass through the gal-

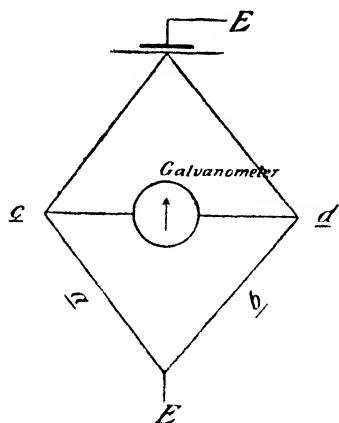


Fig. 1.

vanometer. If, however, a was less than b there would be a transfer of part of the current from d to c , and *vice versa*.

Taking what should be, but is not, the science of electro-physiology as it is to-day, it is a matter of infinite wonderment to me that physiologists have all failed to recognise, from their own works, that the structure of the body is primarily electrical. If it is so one cannot be surprised, in the absence of such recognition, that the practice of electro-therapeutics is empirical. A necessary preliminary to curative treatment is knowledge of the human neuro-electrical system—the generator or generators of nerve-force, the natural conductors and dielectrics, the condensers and storage cells and their capacity, and, what is of paramount importance, the influence of disease upon any or all of them. Until that knowledge is acquired treatment cannot be said to rest upon a scientific basis. I do not, of course, include the surgical uses of electricity

of high potential, but I do most emphatically refer to high frequency—except as a species of electro-massage—to local and general faradisation, to central and local galvanisation, and the rest of it. I also venture the opinion that we know next to nothing of the electro-pathology of disease, that we have no recognised method of electro-diagnosis worthy of the name, and that by reason of the errors of the past and the consequent unreliability of the data already obtained, we should lose little or nothing if we forgot everything we had learned, and made a fresh start under improved conditions of research.

Let us examine, in the light of what we claim to be the discovery of a fundamental truth, structures of the body as illustrated and described in modern and accepted works upon Histology and Physiology, and see what we can learn from them.

With the evolution of body organs and structures, the electrician has no concern and can pretend to no knowledge. That is not his department. He can only examine them in their completed condition, interpret them as they appear to him, and give such explanations of their construction and functions as are consistent with established physical laws. If his conclusions are based upon truth, and not upon mere theory or sophistry, they should not, cannot, conflict with any established law, but must serve to make clear that which is at present obscure.

As a first step we should, I think, consider the nature of the nerve-current. To this day no one knows whether in a galvanic cell electrical begets chemical action, or whether the force we call electricity is generated by chemical decomposition. There is nothing in the form and appearance of the galvanic cell to afford the proof or even to guide us to definite opinion. That is not so with the human body; we are not at that disadvantage. To the careful observer the structure of the human body must

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appear to be *primarily* electrical and to be designed for the performance of electrical functions, not necessarily outweighing in importance those chemical changes which are essential to life, but taking precedence of them.

CHAPTER V

THE NATURE OF THE NERVE IMPULSE

"It may be supposed that some electrical function is exercised by oxygen in the blood."—*Sir Humphrey Davy*.

THE controversy which arose years ago between the physiological and physical schools as to the nature of the nerve impulse has, so far, contributed nothing decisive to our knowledge of the subject.

"Theories there are in plenty, but none of them adequate to explain the phenomenon." (Halliburton, 1915.)

The facts which, we are told, make a chemical theory acceptable are—

- "(1) Analogy with muscle, where the propagation of the muscular impulse is undoubtedly largely due to the propagation of chemical disturbance.
- "(2) Evidence that the nerve does undergo metabolic changes, as shown by the necessity for oxygen, and the production of minute amounts of carbon dioxide.
- "(3) Arrhenius and Van't Hoff showed that a rise of 10° in temperature increases the velocity of a chemical reaction to two or three times its original rate. . . . Maxwell's recent experiments show that a rise of 10° C. approximately doubles the velocity of nerve conduction. . . . Woolley obtained the same figure from the influence of temperature on the rate of conduction in muscle, so probably the conduction process is of a similar nature in both tissues." (Halliburton, 1915.)

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* All this is in perfect harmony with the hypothesis that the impulse is neuro-electrical. The effect of a rise of temperature upon liquid or semi-liquid conductors is to decrease their resistance, or, in other words, to increase their conductivity. It is purely to my mind a question as to which action is precedent, the electrical or the chemical, and I do not think that anyone can, after careful study of the structure of muscular tissue, ganglia, and nerve, doubt that it is the electrical.

The physical theories in relation to this question compare the nerve impulse to the way in which an electrical charge is propagated along a wire, and, in refutation, the slow rate of conduction in nerve and the phenomenon of inhibition are adduced.

Now, it is incontrovertibly true that nerve-current will flow along a metallic conductor, but it is abundantly evident that instead of being homogeneous, as a wire is, the conductors of the body are complex. Halliburton tells us that a nervous impulse does not necessarily travel along the same nerve-fibre all the way, and that there is a *system of relays*. He adds that on the onward propagation of a nerve impulse through a chain of neurons its passage is delayed at each synapse, "hence there is additional 'lost time' at each of these blocks." And there are very many of them.

Suppose that, instead of an electric circuit being composed of an insulated cable, it was made up of thousands of cables and wires and many thousands of condensers of varying capacity. Would the velocity of the current be the same? It would not. There would, inevitably, be some "lost time" at many of the condensers by reason of their not receiving instantaneously their full tension charge, and owing to varying degrees of retardation.

To postulate that the nerve impulse is *not* of an electrical nature is to accuse Nature of introducing into the body

certain processes which are useless to man ; I refer to insulating processes. If their existence is disputed, I can only reply that proof of their presence is to be found in recognised works on Physiology. Let me make that clear. Assume that we do not know anything about the nature of the nerve impulse, and consider only the behaviour of nerves under electrical stimulus or irritation. My authority is Professor Rosenthal, who, in his *Physiology of the Muscles and Nerves*, writes as follows : “ If the main stem of a nerve is irritated by electric shocks, all the fibres are invariably simultaneously irritated. On tracing the sciatic nerve to its point of escape from the vertebral column, it appears that it is there composed of four distinct branches, the so-called roots of the sciatic plexus. These rootlets may be separately irritated, and when this is done contractions result, which do not, however, affect the whole leg but only separate muscles, and different muscles according to which of the roots is irritated. Now, as the fibres contained in the root afterward coalesce in the sciatic nerve within a membrane, it follows that the irritation yet remains isolated in the separate fibres and is not imparted to the neighbouring fibres. This statement holds good of all peripheric nerves. *Wherever it is possible to irritate separate fibres the irritation is always confined to these fibres and is not transmitted to those adjacent.*” *

Now, the sciatic nerve is composed of a number of bundles of nerve-fibres (some efferent, some sensory). If each one was not separately insulated it would be impossible to irritate one fibre electrically without simultaneously irritating all the others. Not only is this so, but each bundle is protected from inductive interference by a lymph space directly under the perineurium and corresponding to the copper taping of telephone or telegraph

* The italics are mine.

conductors. Of what use is all this if nerve impulse is not of an electrical nature ?

Professor Rosenthal admits that the nerve substance offers resistance to the passage of the nerve impulse. He says : " It is probable that the propagation proceeds at first at a greater and afterwards at a less speed," basing this opinion upon Munk's experiments. " Its propagation is gradually *retarded*. . . . From this it may be inferred that a resistance to the transmission exists within the nerve, and this gradually retards the rate of propagation."

Reverting to the question of peripheric nerves, he goes on to say that transmissions or irritation from one fibre to another occur within the central organs of the nervous system. " But in these cases it can be shown with great probability that the fibres not only lie side by side, but that they are in some way interconnected " (ganglion-cells or synaptic junctions) " by their processes. In peripheric nerve-fibres the irritation always remains isolated. Their action is like that of electric wires enclosed in insulating sheaths. One of these nerves may indeed be compared to a bundle of telegraph wires, which are protected from direct contact with each other by gutta-percha or by some other substance. The comparison, however, is but superficial. No electrically isolating membrane can really be *discovered* in any part of the nerve-fibre, but all their parts conduct electricity. When, as we shall find, electric processes occur within the nerve, these standing in definite relation to the activity of the nerves, we must assume that isolation as it occurs in the nerves is not the same as in telegraph wires. We cannot trace the matter here further, but must accept the fact of isolated conduction as such, reserving its explanation for a future occasion."

Its explanation does not appear to me to present any feature of difficulty. The endoneurium of a nerve-fibre—and I am adhering to the sciatic nerve—may be said to

correspond to the gutta-percha covering of the telegraph wire, but in the case of the telegraph wire as in the nerve-fibre an electrically isolating membrane really exists; all their parts conduct electricity, and conduction is merely a matter of degree. A substance which will not conduct low tension may be an excellent conductor of high-tension electricity, and there is an enormous difference between the human electromotive force of four or five millivolts and the voltage of an induction shock.

As regards electric processes occurring within a nerve we have in a nerve the process of intra-cellular action, which does not take place in a wire in the same way or to anything like the same extent, even if it occurs at all. There are many points of similarity between nerve-circuits and telegraph-circuits, but the two are not identical.

In regard to inhibition it is at least conceivable that by the action of certain ganglion-cells an opposing E.M.F. is set up in or communicated to a nerve-fibre or fibres so as to produce a lessening of action or diminution of impulse. It is known that "an impulse will in some cases travel both ways." This would necessarily occur in a circuit in which there was inductive capacity, and a mere cursory examination of such physiological diagrams as show the direction given to nerve impulses by different combinations of ganglion-cells in sensory and motor paths should sufficiently convince the student that such action does occur.

Macdonald reduces the phenomenon of nervous conduction to electrolytic dissociation and association of inorganic ions, but I fail to see how this can be caused by potassium salts in organic combination within the axis cylinder, as suggested by him, though some such action may occur within a cell. A more reasonable explanation is electrical action set up between oxygen and some element electro-positive to it in the cell contents.

“ It is interesting to state, if only in outline, the kind of theories which are in the air at present. We must await with patience to see whether they or any of them contain a germ of truth, or whether, like so many theories in the past, they will be forgotten in the future.” (Halliburton, 1915.)

That is tantamount to a confession that the chemical theory is not altogether satisfying. Once, however, we understand the law, our knowledge of the full application of it will only involve some further microscopic and galvanometric research, with our eyes wide open, to find the something which exists but which we have not seen, for the simple reason that we have not been taught to look for it.

In regard to the analogy with muscle it must, I think, be admitted on the face of the evidence I shall bring forward that the structure and operation of voluntary muscular fibre offers a very strong proof that muscular impulse is primarily due to the propagation of neuro-electrical, and not chemical, disturbances. I cannot, in fact, find any physiological argument which is not more in favour of electrical than of chemical action. Explanation of the latter is often laborious and unconvincing, whereas the former is always and in every detail harmonious.

The velocity of the nerve impulse in man is said to be about 120 metres per second. Now, the apparent velocity of an electrical current is diminished more or less in proportion to the capacity of the circuit; the higher the capacity the lower the velocity, due to retardation. A cable is a homogeneous structure, in the sense that in the circuit of which it forms a part there are no, or very few, “ synaptic junctions ” to occasion delay.

In the human body the velocity of the nerve impulse is not everywhere the same, nor could it be so unless the

inductive capacity was uniform throughout, and this, obviously, is not the case.

Retardation, or the portion of the current retained upon the surface of the wire, is also dependent upon, among other things, the length and diameter of the wire or, in other words, upon its resistance. And here note should be taken of the fact that the effect of capacity is to produce *prolongation* at the end as well as *retardation* at the commencement of a current ; so that a current takes longer to leave the line than it did to enter it.

"In nerves," I learn from Landois and Stirling, "the resistance is two and a half million times greater than in mercury, while in animal *tissues* it is almost a million times greater than in metals." Taking the specific resistance of copper as 1, mercury (at 57°) is approximately 50, so that the resistance of the nerve, taken longitudinally, would be 50,000 times greater than that of copper. For liquids the resistances are enormous as compared with metals, and they are subject to chemical decomposition or change in the process of conduction.

It is, of course, extremely difficult, if not impossible, to calculate accurately the resistance of a living nerve relatively with that of a copper wire unless we are given the exact sectional area of the nerve-conductors, and, probably, not even then. But for curiosity's sake it may be well to see how the 50,000 times increase of resistance works out.

We will take two round pure copper wires of sectional areas of 0.01 and 0.02 in. respectively, and suppose them to be two nerves of the same diameter.

The resistance of a copper wire of 0.01 in. corrected to 100° F. is 0.3677 ohm per metre, and if we, for convenience of calculation, take the maximum length of a nerve to be 2 metres, we have $0.3677 \times 2 \times 50,000 = 36,770$ ohms as its total resistance, or $\div 6.5 = 5,657$ ohms per ft. length

Similarly the wire of 0.02 in. section with a resistance of 0.0884 ohm per metre would give us 8,840 ohms total resistance and 1,360 ohms per ft. length, and while this brings us no nearer to the actual resistance of a *nerve*, it approximates somewhat to the resistance of the hand-to-hand *circuit*, in which, by reason of the absence of sebaceous glands in the palms of the hands, skin resistance is much lower than in most other parts of the body.

This conclusion is arrived at in the following manner:—

Upon the scale of a reflecting galvanometer which has a sensibility of 4,000 mm., at a metre distance from the scale, per micro-ampere, the average hand-to-hand deflection of a person in normal health is between 300 and 400 mm., equivalent to a current of from 0.08 to 0.1 micro-ampere.

The mean of several thousands of tests has shown the electromotive force of man to range between 4 and 5 millivolts, and, as $C = \frac{E}{R}$, we can, knowing C and E, calculate R with some approach to accuracy. By this method we should find the resistance of the hand-to-hand circuit to be over 5,000 ohms, taking into consideration the difference of sensibility or response to current and voltage. The calculation, however, is not given with the confidence that would attach to a bridge test in which the natural current was used, to the exclusion of battery power.

5,000 ohms would be lower by 3,840 ohms, or 590 ohms per ft. length, than the wire of 0.02 in. sectional area, but in the circuit in question there are several conductors, and among them the main leads of the thumbs.

The resistance of nerves, whatever may be their expression in ohms, must vary in many parts of the body, and, irrespective of the surface area of the conducting plates or discs or rods of the body condensers, have the effect of altering capacity; while further variations are introduced by the inconstancy of the human electro-motive

force and differences in the nature or chemical composition of the insulating substance.

Even when in two condensers the conducting plates are of equal surface-area, are equidistant, and E.M.F. is constant, it does not follow that their capacity will be the same. Suppose the dielectric of one to be paraffin and of the other gutta-percha. The specific inductive capacity of air being taken as 1, paraffin is 1.99 and gutta-percha 4.2. It will, therefore, be seen that upon charging these two condensers to the same potential difference the condenser with the gutta-percha dielectric will receive a charge about 2.1 times greater than the condenser with the paraffin. Moreover, capacity depends also upon the *thickness* of the dielectric, in the inverse ratio.

As regards a comparison of the capacity of the human body with that of a submarine cable, the average capacity of the latter ranges at about 0.3 microfarad per knot, while I have found the former, using the same battery-power, to be nearly 4 micros. Its absolute insulation resistance is, however, comparatively low, and charge is not, therefore, retained.

I extract the following from one of my old note-books:—

“When the body was charged for fifteen seconds with fifteen cells the immediate discharge (with 30 ohm shunt) was 220 mm. Again charged for fifteen seconds and insulated for sixty seconds, the discharge was 36 mm., and upon this being repeated many times it became evident that by reason of the low absolute insulation resistance of the body the charge was given off to air in a short period of time. As a result of this and another series of tests with earth connections, I find that the body, when insulated, does not act as a plate of a condenser as regards the earth, but that the body itself acts *in every respect* as a condenser of low insulation.” But there is this to be said: *the quantity of the charge communicated to the plates depends directly*

*upon the electromotive force of the cells used.** In the tests to which reference has been made the electromotive force was 20 volts. The average electromotive force of man may be put at a maximum of 5 millivolts, so that the quantity of the charge with 20,000 millivolts would be many times greater than with 5 millivolts, and this, I think, suggests (1) that although the insulating processes of the body are not adapted to withstand the strain of high tension (and capacity is regarded as a strain upon the dielectric), they are adequate for the purposes for which they were designed; (2) that the body can be inductively influenced by any outside source of electrical energy of a potential appreciably higher than 5 millivolts; and (3) that as the quantity of current exhibited by a healthy man may be expressed as being less than 1 micro-ampere, we are justified in assuming that the law of retardation applies with equal force to the human organism.

In the elaboration of my theory of the nature of the nerve impulse, *i.e.*, that it is neuro-electrical and due to the association of iron as the positive and oxygen as the negative element, in the presence of an exciting liquid, I was confronted by the fact that I could not, as an electrician, recognise or point to any organ in the body which could be said to be a generating *station*. I am indebted for what may be the missing link to a communication from Dr. E. W. Martin, from which I shall presently take the liberty to quote. Before doing so, however, it may serve a useful purpose—as this work is intended for the guidance of those who are not familiar with applied electricity—to offer a few observations upon so-called *positive* and *negative* currents; my authority being the text-book of *Telegraphy*, by Preece and Sivewright.

“A current is always supposed to flow from the point of higher potential to that of lower potential. The former

* See also p. 91 *et seq.*

point is taken to be positive to the latter ; and, *vice versâ*, the lower is taken to be negative to the higher point. The terms positive and negative *currents* are frequently used, but they are misnomers. There is only one current flowing and it varies in direction. It is quite correct to apply the term positive or negative to currents *with respect to a given point*, and by those terms to imply *direction only*, for while stationed at a given place currents may flow *from* or *towards* us ; but what is a positive current at one point is a negative current at another. . . . A current can only be *constant* when we have two points separated from each other by an invariable resistance, and *maintained* at the same difference of potential."

We shall see, later on, that in the human body neither the resistance of any given circuit nor the same difference of potential can be maintained owing, quite apart from disease, to variations of external temperature and the fluctuating nature of the human electromotive force ; and the fact is emphasised that in the estimation of body deflections we must have a fixed point of departure, and that that point should be upon the central line.

We will now consider Dr. Martin's letter upon "The Source of Body Energy and its Relation to the Nervous System."

He says : "The theory of neuro-electricity, galvanometric tests, and treatment, founded upon the theory propounded by Mr. Baines, has proved of value in the treatment of certain conditions of disease. The argument, therefore, follows that the basis of the theory is sound. In detail, however, the original conception of the brain as a generator, and the nervous system as a carrier, of a constant current came into collision with established physiology, and endangered the hearing of a piece of scientific work of great value.

"I advance a theory which may be an explanation, and

which, if proved to be correct, will range the physiologist and the electrical expert on the same side, while adding a fresh conception of the body as a whole in relation to one source of life ; at the same time enabling us to more easily understand galvanometric readings of the body energy and to interpret them rightly.

“ As a foundation of the theory, I propose to start from one fact which, when analysed, may lead to a more correct conception of our source of energy. . . .

“ The question raised is one which, so far as I can see, must be answered by those who would explain ‘ neuro-electricity,’ equally with those who deny its existence.

Argument—

“ The conditions before the birth of a child, and immediately after birth, offer a field of thought. What is it that enables the child to support an existence separate from the mother ?

“ Let us examine the problem, bearing in mind that what we require from the electrical expert’s point of view is (1) a linking up of the body with a source of energy, and (2) an organ that will act the part of *generator*.

“ Before birth the fœtus is alive, but nutrition, growth, development, are carried out by the action of the maternal blood-stream. Circulation through the fœtus is established, with one important exception : *there is no circulation through the lung*.

“ Digestive organs, nervous system, etc., are present, but are functionally in abeyance till the act of birth has taken place. What, then, is the difference ? *It is the act of breathing* which determines the separate existence of the child from the mother.

“ Before this act has taken place the lungs contain neither blood nor air. Their function could not be called into play until the need arose to link up the life with its future source of energy.

“The act of birth, therefore, brings with it the power to use a mechanism by means of which the oxygen of the air can be used by the body. From that moment the whole of the latent mechanism is in working activity and the individual life is complete.

“Here we are at one with known facts. Let us now examine the electrical problem in this light. We have seen that we require (1) a source of energy, and (2) an organ to act as generator ; *i.e.*, an instrument or apparatus which, when supplied with material, will generate force.

“We have found the source in oxygen, and the organ in the body to use it ; let us see whether it is possible to carry this analogy further.

“In the lung the state of things is—air vesicle and capillaries, the interchange between blood and air being oxygen from the air to the blood to enter into combination with the hæmoglobin (an iron-containing substance), and CO_2 from the venous capillaries going outwards to air.

“Now, any change between air and blood *must take* place through the wall of the capillaries, and the physiological fact of the permeability of membranes at once arises. Professor Bayliss’ *Physiology*, and I think, quoting from memory, that the work on this subject has chiefly been done by Professor Sherrington, states that the absorption by colloid surfaces depends on the electrical sign of the surfaces and the substance absorbed, and is more an electrical than a chemical action. Also the experiments on permeability of membranes depend on electrical balance and the attraction and repulsion of electro-positive and electro-negative ions, and is again a matter of electrical rather than of chemical activity ; although it would, perhaps, be better to say that chemical action follows the electrical or ionic movement.

“Having found one possible source of energy, one

generator, and the medium for the conveyance of energy, let us next look at the distribution.

“The order of distribution seems to bear some significance—

“1st.—The heart muscle. Remembering the structure of heart muscle, its ganglia, and the function performed by the heart, the call for and supply of this organ with energy is paramount.

“2nd.—Next in order of supply and importance is the nervous system.

“3rd.—The other tissues and organs of the body.

“The order from the generator is, therefore, the pump for circulating the carrier, then the nervous system, whose chief function, *through the sympathetic*, is the regulation, by vaso-motor and vaso-inhibitory nerve-fibres, of the blood supply to all tissues and organs; and if we substitute the word ‘energy’ for ‘blood’ we can follow the thought through. This control is important in disease, as it gives the power to send more blood to the area attacked, and the converse is equally important as explaining a fallacy in galvanometer testing, as I will show later.

“The voluntary system (apart from sensation) has chiefly to do with the movement or the control of muscular contraction resulting in movement. Striped muscle, *i.e.*, the muscles under the control of the voluntary system, will to the electrician at once suggest an electrical apparatus which can be set in motion on being connected up.

“If, therefore, the nervous system, sharing the common energy of the body with every other cell and organ, has a *special* function of control to perform, *it must have some* form of insulation or this energy would be dissipated through moist tissue, and the control of blood supply and the movement of muscle would be lost. It is probable, indeed I think established, that the electrical balance of each cell membrane throughout the body, and the resulting life of the cell, are under the control of and kept in balance

by the sympathetic nervous system ; and that this is so is again an argument in favour of an insulation, without which stability could not be obtained.

“ There may be fallacies which I am unable to detect, but my belief is that in the normal state in quiescent nerves there is an electrical equilibrium, that current passes only on liberation of impulse from brain centres—in the case of the sympathetic from emotion at one end and from irritant at the other—and that, to control this discharge of energy, insulation is imperative and will be demonstrated. To experiment with a cut nerve opens the road to many flaws which are obvious.

“ From Mr. Baines’ point of view it is necessary to prove this insulation. That impulses pass along a nerve is granted, but that this impulse is in the nature of an electrical impulse has to be shown ; but to object because the word ‘ current ’ is used instead of ‘ impulse ’ seems an unnecessary obstacle to understanding, for the nature of a current may be interrupted as well as continuous.

“ The whole arrangement of the nervous system, nodes, synapses, medulla, sheath, ganglia, etc., points to an electrical system with many makes and breaks, shunts, etc., and we have shown before that the *fundamental energising of the body is an electrical phenomenon*.

“ Returning to the blood-stream and for the moment leaving out the specialised organs and glands, we come to the question of connective, fibrous, and elastic tissues.

“ Subcutaneous and other vascular connective tissues may be regarded as the padding of the body. We have a multitudinous cell-life, vascularity, and a controlling nerve supply. Here, then, we have a storage of energy separate from the closed circuit of the nervous system ; closed in relation to the other tissues of the body. In this tissue, as in the specialised organs, the interchange from blood to cell goes on, but in this case we get some diffusion through

moist tissues and only partial insulation by the skin. This no doubt gives us the average reading on the galvanometer scale of ordinary normal deflections, except in the case of the finger-tips and toes, which give constant readings and are probably the earth (air) outlets of the nervous system.

“ At the finger-tips, no matter how dry the skin may be, we are always able to measure a current. Also reversal of sign is obtained from hand to hand and from the thumb to the fingers of the same hand.

“ With other portions of the skin over the body a comparatively dry condition will lead to no current being obtained, while moisture will produce a current equal in E.M.F. at any part.

“ In testing the body as apart from the hand-to-hand measurement, Mr. Baines uses a larger electrode to a fixed point and goes over the body with one of smaller diameter. By this means the sign, which is unimportant, remains the same, and it becomes easier to estimate the deflections due to faulty condition. It has been claimed that these currents are ‘ skin currents ’ and that a metal electrode of larger size, with moist skin, will set up a current, and that the use of electrodes of similar size will lead to different readings, change of sign, etc. I have elsewhere shown that skin and metal to skin and metal through the galvanometer does not always exhibit current, so we must look further for an explanation.

“ If we note the different thicknesses of the skin, apart from pressure areas, we find that where the greatest depth of connective tissue is, or where there is greatest vascularity, the skin is, as a rule, thicker ; and that even in specially vascular areas, like the scalp, there is a special arrangement of skin and connective tissue, we are able to trace in it some purpose. If, then, we remember the fact that the developing foetus is open, and that later it is joined down the centre line, and that fibrous tissue is a non-conductor, we

at once can see that by using electrodes of a similar size we should frequently obtain change of sign, which is avoided by adopting Baines' method.

"Mr. Baines has pointed out that, in testing, a slow excursion, say to 200 mm., is met with which may be mistaken for a leakage from the nervous system. Anyone using the galvanometer will soon learn to judge this condition; *quantity* as evidenced by the *rapidity* of excursion being the test of a nerve flaw.

"If the theory advanced of the source and distribution of energy is correct, this false reading can be explained. A local vaso-motor disturbance would result in increased blood supply. For this read conveyance of energy, and at once you have a local increase of potential, and the skin insulating for a normal potential only, will allow of the larger escape and give an excursion, but without the quantity of a leakage from the insulated nervous tracts where the potential is probably higher.

"It will be understandable that the readings from this cellular source of energy are comparatively unimportant, and that the larger electrode may be used to govern the direction of the flow without in any way interfering with the usefulness of the readings.

"An escape through a flaw in the insulation of a nerve would result in diffusion, through moist substance, of a current of much greater quantity, and give the rapid deflection of larger extent which one has learned to associate with a genuine alteration in tissue metabolism."

Unfortunately, as I have said in another chapter, our knowledge of condenser action in the body is limited by the absence of information regarding the specific inductive capacities of natural dielectrics. With special reference to the velocity of the nerve impulse the experiments of Dr. Le Bon are of importance. He came to the conclusion that electricity is able to propagate itself in insulators as

well as in conductors, but much more slowly in the first case than in the second, the velocity varying from *a few centimetres* to 300,000 kilometres per second. In the enormous margin between the two there is ample room for speculation as to the causes which contribute to the comparative sluggishness of the human nerve-current.

The same authority showed that the particles emitted by an electrified point were identical with those which came forth from radium ; suggesting, by inference, that the force known as electricity may be made up of more than one form of energy.

CHAPTER VI

INDUCTIVE CAPACITY

As a good deal depends upon a proper appreciation of the function of a condenser, as that apparatus is used in telegraphy, it may be well to make it clear ; taking as my authorities Sir Wm. Preece, F.R.S., and Sir James Sive-wright, joint authors of *Telegraphy*.

“ When a quantity of electricity flows through a line in the form of current, the first portion of the current is retained or accumulated upon the surface of the wire, in the same way that a charge is retained or accumulated upon the surface of a Leyden jar. The quantity accumulated depends (1) upon the length and diameter of the wire, (2) upon its distance from the earth and earth-connected bodies, (3) upon the insulating medium surrounding the conductor.

“ The effects of capacity are, first, that it absorbs all the electricity of a short momentary current and prevents the appearance of any current at the distant station, and, second, that as it absorbs the first portion of every current sent, it has the same effect as if it *retarded* or delayed the first appearance of the current at the distant end. Thus the apparent velocity of the current is diminished more or less in proportion to the capacity of the circuit, velocity being in the inverse ratio to the capacity.

“ ‘ Condenser ’ is a term applied to an apparatus usually composed of alternate layers of tinfoil and paraffined

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paper, so arranged as to form a flat Leyden jar of large surface, and constructed to give any capacity that may be required. It may be shown thus—

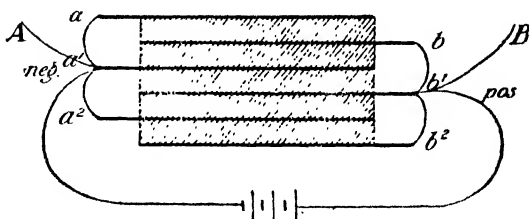


Fig. 2.

a, a^1, a^2, b, b^1, b^2 are square pieces of tinfoil separated by sheets of thin paper steeped in melted paraffin wax. The series a, a^1, a^2 are connected together, and so are the series b, b^1, b^2 . A and B thus become connected with what may be regarded as the inside and outside coatings of a Leyden jar, and by putting one pole of a battery to A, and the other pole to B, we can communicate a charge to the plates the quantity of which will depend (1) directly upon the electromotive force of the cells used, (2) directly upon the total surface of each series of conducting plates opposed to each other, (3) inversely as the distance between each pair of plates, and (4) upon the nature of the insulating material used to separate the conducting plates."

Condensers are conventionally represented by parallel lines, *i.e.*—



Fig. 3.

Now, the electrostatic capacity of a line is unequally distributed, and its working conditions are naturally affected by this distribution. A circuit may be made up

of overground wires, underground wires and cables; and one of the principal functions of a condenser, or of a series of condensers, is in telegraphy to compensate for and regulate this inequality of distribution. In the human body, whose circuits are infinitely more complex than the most complicated telegraph system, they are not only designed for the performance of this function, but for the equally important one of changing the sign of current from efferent to afferent, or *vice versa*.

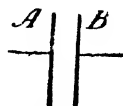


Fig. 4.

“A simple condenser is, as we have seen, shown in Fig. 4. If we connect that to a galvanic cell (Fig. 5) the charge communicated to plate A will (if the plates are of the same area) induce a charge of equal tension but of opposite sign upon plate B.

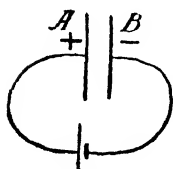


Fig. 5.

“The capacity varies directly as the surfaces of the opposing plates. If, now, three condensers F_1 , F_2 , F_3 , be joined up as shown by Fig. 6, the effect is clearly to connect all the A plates together, so that, practically, they become

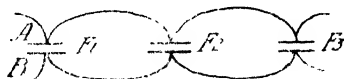


Fig. 6.

one plate of large area, and so also with the B plates; hence, by such an arrangement, the total capacity (F) becomes

$$F = F_1 + F_2 + F_3$$

and the condensers are said to be connected in parallel.

“Again, the capacity varies inversely as the distance between the plates. Assume the distances in the following

figure to be $\frac{1}{F_1}, \frac{1}{F_2}, \frac{1}{F_3}$; then, if the three condensers be joined as shown, the B plate of F_1 is practically brought

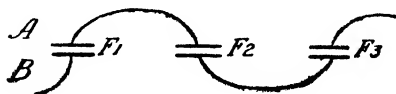


Fig. 7.

opposite that of F_2 , by the connection of the A plates of F_1 and F_2 , but at distance $\frac{1}{F_1} + \frac{1}{F_2}$, and similarly with F_2 and F_3 , so that the distance between plate B of F_1 and plate A of F_3 is $\frac{1}{F_1} + \frac{1}{F_2} + \frac{1}{F_3}$; and the capacity (F) is therefore

$$F = \frac{1}{\frac{1}{F_1} + \frac{1}{F_2} + \frac{1}{F_3}} \quad "$$

When condensers are connected in series their joint *capacity* is the reciprocal of the sum of the reciprocals of their respective *capacities*, while in parallel the joint *resistance* is equal to the reciprocal of the sum of the reciprocals of their respective *resistances*. In voluntary muscular fibre the sarcomeres are, in my belief, joined up in groups in series as well as in parallel, and it may serve

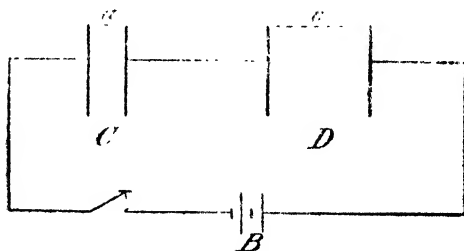


Fig. 8.

a useful purpose to append a practical illustration or two from *Submarine Cable Testing and Working*, by my namesake, G. M. Baines, of the Eastern Telegraph Company.

Let C and D (Fig. 8) represent two condensers with capacities of 15 and 5 microfarads respectively, and B cells of an electromotive force of 3 volts; the distance between the plates of C being equal to a and between those of D equal to b .

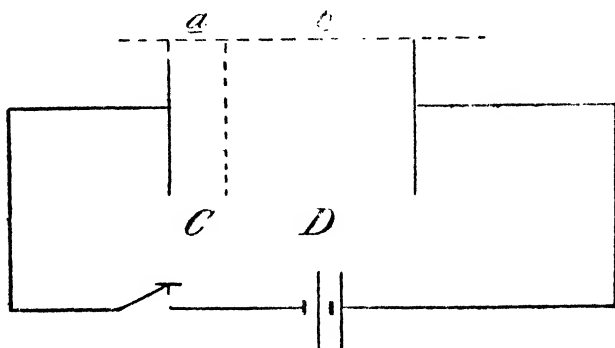


Fig. 9.

In the above figure the same pair of condensers show under the conditions which actually regulate the test of their joint capacity; the inner plates of both having been eliminated.

C and D are now, to all intents and purposes, a single condenser with, it is important to observe, a distance between its plates equal to $a + b$. Without calculation it will be recognised that the joint capacity of the pair must be smaller than the capacity of either of them if tested alone, because of the increased distance between the plates.

Upon closing the battery circuit the outer plates of C and D are equally and oppositely charged to the potential difference of the battery, *viz.*, 3 volts. When this potential difference has become established, the current from the battery *will cease to flow*. The neutral condition of the inner plates of C and D has, meanwhile, been disturbed by

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the inductive effect of the battery charge, and quantities of electricity equal to that charge, but of opposite sign to each other, will be collected upon the inner plates ; these, however, and therefore their electrical condition, do not in any way influence the *joint* capacity of the two condensers, which in accordance with the law must be

$$\frac{1}{\frac{1}{15} + \frac{1}{3}} = \frac{1}{\frac{2}{15}} = \frac{15}{2} = 7.5 = 3.75 \text{ microfarads ;}$$

the charge being $3.75 \times 3 = 11.25$ microcoulombs, and the potential differences of the charges on C and D 0.75 volt and 2.25 volts respectively.

Similarly the charges on three condensers of varying capacities, and connected in series, as also their potential differences, may be shown by employing three glass vessels for the purpose ; the larger the vessel the greater the capacity.

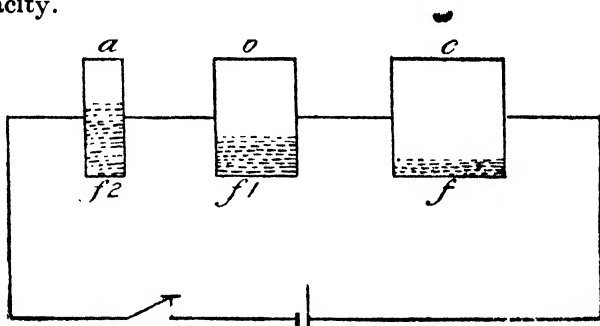


Fig. 10.

a is $\frac{1}{3}$ and b $\frac{2}{3}$ the size of c , and we will call the respective capacities 2, 4, and 6 microfarads and the E.M.F. of the battery 2 volts.

The joint capacity of a , b , and c will be—

$$\frac{1}{\frac{1}{2} + \frac{1}{4} + \frac{1}{6}} = \frac{1}{\frac{11}{12}} = \frac{12}{11} = 1.1 \text{ micros.}$$

The charges on the three condensers will be exactly the

same in amount, but their potential differences will vary in proportion to the plate areas f , f_1 , and f_2 .

In a the charge has only a surface of 2 microfarads over which to diffuse itself; consequently, as this surface is the smallest of the three, the potential difference of its plates will be the maximum. In b it will be only half as great as in a , while in c it can only be equal to $\frac{b}{2}$ or $\frac{a}{3}$.

The sum of the potential differences should equal the E.M.F. of the battery, and would work out as follows:—

$$\begin{array}{rcl} a & = & 1.091 \text{ volts (about)} \\ b & = & 0.545 \text{ volt} \\ c & = & 0.364 \text{ „} \\ \hline \text{Total} & & 2.000 \text{ volts} \end{array}$$

It will thus be seen that to raise a to the same potential difference as c , only one-third of the charge it has accepted in series would be required. Similarly the joint capacity of any number of condensers of equal capacity connected in series is the capacity of any one of them divided by their number.

It will also be seen why, if the sarcomeres of voluntary muscular tissue are joined up in series, it can only be in limited groups of them, otherwise capacity and potential difference would approach the vanishing point before the initial impulse had travelled very far. That connection is made in this manner, *i.e.*, in series-parallel, will be apparent when study is made of the terminations of nerves in muscle (p. 150).

We have now learned some very important facts, *viz.*—

(1) That capacity varies directly as the surfaces of the opposing plates, (2) that the velocity of the current is in the inverse ratio to the capacity, and (3) that capacity varies inversely as the distance between the plates. That being so, it follows: (1) the larger the plate-area the greater

the capacity, (2) the greater the capacity the lower the velocity of the current, and (3) the closer the conducting plates are together the greater the capacity.

In the human body none of the conducting plates, discs, or points are of large area, but while no considerable variation of capacity is possible by this means, Nature can, and apparently does, overcome the difficulty by approaching the conductors closely to each other, as in striated muscular fibre, and by connecting them sometimes in parallel (as in Fig. 6). In other parts of the body structure—in various arborisations, for instance—there must be differences of capacity and resistance, and therefore velocity of current or nerve-impulse cannot be uniform throughout the whole of the nervous system.

This is an opinion arrived at after experiment and careful thought, and I am encouraged to find myself supported in the view by several authorities. Halliburton says: "The rate of stimulation makes no difference; however slow or fast the stimuli occur, the nerve-cells of the central nervous system give out impulses at their normal rate.

"The same is seen in a reflex action. If a tracing is taken from the gastrocnemius of a pithed frog, the muscle being left in connection with the rest of the body, its tendon only being severed and tied to a lever, and if the sciatic nerve of the other leg is cut through, and the end attached to the spinal cord is stimulated, an impulse passes up to the cells of the cord, and is then reflected down to the gastrocnemius under observation. The impulse has thus to traverse nerve-cells; the rate of stimulation then makes no difference; the reflex contraction occurs at the same rate, 10 or 12 per second . . . recent experiments by Piper . . . he found that each wave of the curve obtained by the graphic method is really itself due to fusion of contractions occurring at a more rapid rate. The method

he employed was to count the number of electrical variations which accompany a voluntary contraction, on the assumption that each fundamental unit of the contraction has an electrical change as its concomitant. . . . The number of electrical variations is found to be a fixed one for each muscle, but to vary in different muscles. Various spinal and cranial motor centres have thus different rhythms, and of those hitherto studied the cells of the motor fibres of the fifth cranial nerve have the highest rate of discharge, 86 to 100 per second. In muscles supplied by spinal nerves the rate is lower, 40 to 60."

Many other proofs could no doubt be cited, but we have an example of, as I think, variation of capacity in *Purkinje's fibres* in the auriculo-ventricular-bundle of cardiac muscle. These are large, quadrangular cells with granular protoplasm, and striated, it is said, only on the margins. The slow rate of propagation of the wave suggests greater capacity than in ordinary striated muscle, and therefore either (1) the plates are closer together, (2) they are larger, or, (3), what is more probable and indeed indicated by physiological diagrams, they are connected in parallel. If this is so the argument should apply with even greater force to plain muscle, but, unfortunately, the structure of the latter is not sufficiently defined to enable a definite opinion to be given.

In cardiac muscle the movement is rhythmical, and it differs from that of voluntary and plain muscle in that, subject to regular periods of rest, it is constant, whereas in the others it is intermittent. We can readily understand this when we remember that discharge or neutralisation does not take place instantaneously unless there is actual contact. Regular periods of time or rest would be necessary in any such circuit if it was required to work continuously and automatically. The retardative action is equally pronounced in the discharge as in the charge, and

both velocity of impulse and periodicity are dependent upon the two factors of resistance and capacity.

It is a pity that we have no data as to the specific inductive capacities of the natural dielectrics of the body, such as cholesterol, neuro-keratin, lecithin, kephalin, the medullary sheath, etc., as a basis for calculation. As against the 1 of air, sulphur is 1.93, but as other dielectric substances range between 1.77 and 10.1, it is evident that further research is called for to determine this important point.

Apart from, but in addition to, specific inductive capacities, I should much like to have the following information :—

In a selected piece of striated muscle—

- (1) The surface area of the clear spaces,
- (2) The thickness of Krause's membrane,
- (3) The average number of sarcomeres connected by the end-plates of motor-nerve fibres, and
- (4) Whether such end-plates do or do not connect the clear spaces thus—

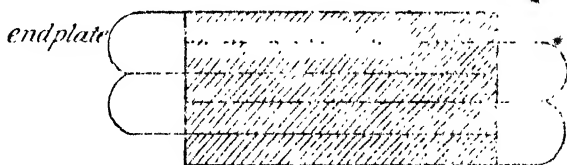


Fig. 11.

That would be something to go on with.

I learn from *The Human Species*, by Ludwig Hopf, that an average size piece of striated muscular fibre measures 20.4 mm. in length by 0.06 mm. diameter. If we had the thickness and specific inductive capacity of Krause's membranes we could, at least approximately, calculate the capacity of each sarcomere.

In plain muscle the figures given are 0·045 to 0·225 mm. long by 0·004 to 0·007 mm. wide. These are given by Hopt. Halliburton states that the fibres of voluntary muscle average about 1 in. in length and $\frac{1}{800}$ (0·05 mm.) in diameter.

TO TEST THE BODY FOR CAPACITY.

There are several ways of doing this, but as extreme accuracy is not required, the most convenient method is by direct discharge. For this a "universal" shunt and a standard condenser of $\frac{1}{3}$ to 1 micro are required, and the subject should stand upon an ebonite slab to obtain good insulation.

Using fairly high power (say 20 volts) at first, and afterwards not more than 0·5 volt, take two sets of observations in the following manner. Charge the standard condenser F_1 by the battery for a given number of seconds and discharge it through a shunted galvanometer. Note the immediate deflection and call it d_1 . Next, charge the condenser to be measured (the body), F_2 , by the same battery; discharge it through the galvanometer and again note the immediate deflection, d_2 . Then—

$$F_1 : F_2 :: d_1 : d_2, \text{ or } F_2 = F_1 \frac{d_2}{d_1}$$

If $\frac{F_1}{d_1}$ is made a submultiple of 10, d_2 gives the capacity at once.

The multiplying power of the shunt or shunts used is found by the formula—

$$G + s$$

G being the resistance of the galvanometer in ohms, and s the resistance of the shunt.

102 STUDIES IN ELECTRO-PHYSIOLOGY :

* The actual connections in my original tests were :—

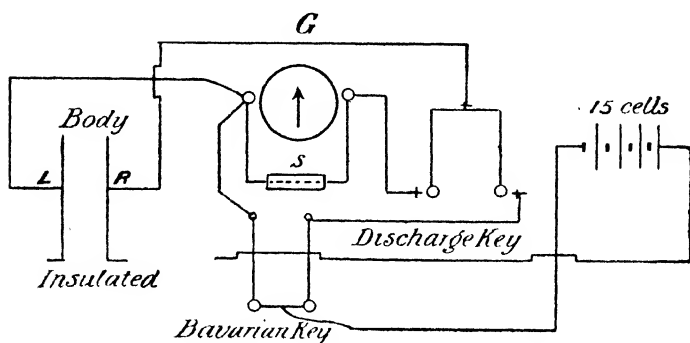


Fig. 12.

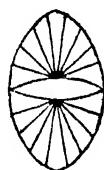
d_1 was taken with a standard condenser of 1 microfarad capacity, a galvanometer resistance of 7,000, and a shunt of 80 ohms. The immediate discharge, or d_1 , was 204 mm., or, multiplied by $\frac{G + s}{s} = 18,033.6$ mm.; while d_2 , with a 30-ohm shunt, was 290 mm., or 67,947 mm. in full. This by the formula $F_2 = F_1 \frac{d_2}{d_1}$ gave 3.76 micros (nearly) as the capacity of the body. In taking this test it is advisable that the observer stands as far from the subject as possible.

CHAPTER VII

CELL REPRODUCTION

MITOTIC DIVISION.—THE CENTROSOME AND THE
ATTRACTION SPHERE

IN a diagram of a cell (Schäfer) the centrosome is shown double and lying near the nucleus. This is a minute particle (*centriole*), surrounded by a clear area (*attraction sphere*) and from it radiate into the surrounding protoplasm a number of fine fibrils and dot-like enlargements at intervals. The twin spheres are connected by a spindle-shaped system of delicate fibrils (achromatic spindle), and this duplication invariably precedes the division of a cell into two.



In the process of division of a cell many changes occur, but it is *always* “*preceded by the division of its attraction sphere*, and this again appears to determine the division of the nucleus.” These changes are, briefly, as follows :—

- “(1) The network of chromoplasm-filaments of the resting nucleus becomes transformed into a sort of *skein*, formed apparently of one long convoluted filament, but in reality consisting of a number of filaments (*spirem*); the nucleus membrane and the nucleoli disappear, or are merged in the skein.
- “(2) The filament breaks into a number of separate portions, often V-shaped, the *chromosomes*. . . . As soon as the chromosomes become distinct they are often arranged radially round the equator of the nucleus like an aster.

- “(3) Each of the chromosomes splits longitudinally into two.
- “(4) The fibres separate into two groups, the ends being for a time interlocked,” *i.e.*, complete division has not taken place.
- “(5) The two groups pass to the opposite poles of the now elongated nucleus and form a star-shaped figure at either pole (*diaster*). Each of the stars represents a daughter nucleus.” At this point complete separation has occurred, and the following appearance is presented (Fig. 13):—



Fig. 13.



Fig. 14.

- “(6), (7), (8). Each star of the diaster goes through the same changes as the original nucleus, but in the reverse order, *viz.*, a skein, more open and rosette-like, then a closer skein, then a network; passing finally into the typical reticular condition of a resting nucleus.” The penultimate stage is shown in Fig. 14 and is the stage immediately preceding the division of the cell.

“The protoplasm of the cell divides soon after the formation of the diaster. During division fine lines are seen in the protoplasm, radiating from the centrosomes at the poles of the nucleus, whilst other lines form a spindle-shaped system of *achromatic* fibres within the nucleus, diverging from the poles towards the equator. These are usually less easily seen than the *chromatic* fibres or chromosomes, but are not less important, for they are derived from the attraction-spheres. These with their centrosomes always initiate the division of the cell; indeed, *they are*

often found divided in the apparently resting nucleus, the two particles being united by a small system of fibres forming a minute spindle at one side of the nucleus. When mitosis is about to take place this spindle enlarges, and as the changes in the chromatin of the nucleus occur—which changes involve the disappearance of the nuclear membrane—the spindle gradually passes into the middle of the mitotic nucleus, and with the fibres of the spindle therefore completely traversing the nucleus. (Fig. 15.)

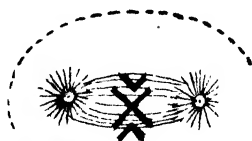


Fig. 15.

“*The spindle-fibres appear to form directing lines, along which the chromosomes pass, after the cleavage, towards the nuclear poles to form the daughter nuclei.*” *

In most animal cells the protoplasm becomes constricted into two parts midway between the two daughter nuclei. “Each daughter cell so formed retains one of the two attraction-particles of the spindle as its centrosome, and when the daughter cells are in their turn again about to divide, this centrosome divides first and forms a new spindle, and the whole process goes on as before.” (Schäfer.)

To go back a little, to the properties of living matter, we learn that “living cells exhibit *irritability* or the property of responding to stimuli,” electrical or otherwise, much in the same way that nerve and muscle exhibit it, and I think we can postulate it as almost, if not quite, unanswerable that to respond to electrical stimulus the structure itself must be to some extent electrical. That it exhibits irritability under mechanical, chemical, or thermal stimuli does not affect the question, because a stimulus of any kind must disturb the equilibrium of an electrical unit of so delicate and sensitive a nature.

* The italics are my own.

It now remains to be seen whether I am in any way justified in applying the term "electrical unit" to any animal cell.

Supposing the single centrosome to be an electrified body, no electrical action of attraction or repulsion could take place within it while it remained *single*, but before any cell-reproduction can begin it is *duplicated*, and duplicated in a very peculiar form, the fibrils having dot-like enlargements at intervals.

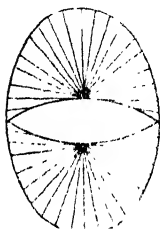


Fig. 16.

In the diagram the dark spots represent the centrioles, and if, as I imagine, they are bodies similarly electrified, the immediate result would be the exercise of repulsion between the two, and consequent elongation of the cell.

Dividing the centrosomes is a clear space over which repulsion would first be exercised.

In Schäfer two diagrams are given to illustrate the changes which occur in the centrosomes and nucleus of a cell during the process of mitotic division:—

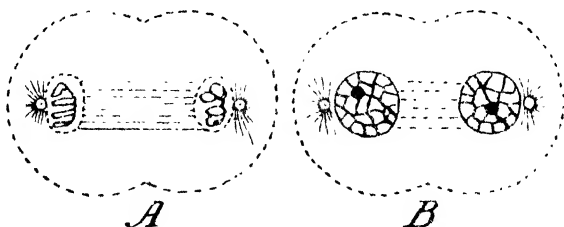


Fig. 17.

Up to the point shown in A, repulsion seems to continue, and we are told that "the spindle-fibres appear to form directing lines, along which the chromosomes pass, after the cleavage, towards the nuclear poles to form the daughter nuclei." It would seem, however, that the repulsive force had reached its limit and that no further elongation of the cell was necessary, because at an intermediate stage

between A and B, while the force was still being exerted, the process of contracting the exoplasm in the middle in order to ensure the division of the cell at that point must have gone on; and in B we see that the lines of force, or the spindle-fibres, are ceasing to exist. That being so, and the cell having divided into two parts, each with its nucleus, nucleolus, and *single* centrosome, it prepares itself for renewed growth and for re-division.

I am, of course, aware that the chemical changes which take place are all important, but they are not in my department, nor am I qualified to deal with them. I am endeavouring, and shall continue to endeavour, to point out that the structure of the body is primarily electrical, and that electrical, or neuro-electrical, action is precedent to chemical change.

And when we know more about their precise connections I am sure we shall find that the nucleus and nucleolus play a very important part in the neuro-electrical scheme of cell-reproduction. In this regard I should like to draw the attention of my readers to that section of this work which treats of ganglion cells in their electrical aspect, and would further observe that in the absence of stimulus or excitement the amoeba assumes, and with it, I take it, all cells assume, a form more or less spherical or ovoid, "elongated, annular, or irregularly lobulated" (Halliburton), which in a condition of rest, or, in other words, prior to change, is their natural shape.

It will be seen also that after the division of the cell has taken place the single centrosome (see Fig. 18) occupies a position close to the nucleus. In that state it is at rest, in the sense that the nucleus is at rest. When, however, the time has arrived for division of the cell to commence the centrosome is seen as in Fig. 19.

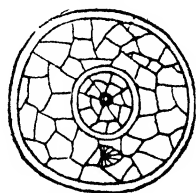


Fig. 18.

At first sight one might be inclined to think that its position is not in favour of the hypothesis I have advanced, because—if the diagram correctly represents its position, as I cannot doubt it does—the repulsive force would be exerted longitudinally, and in such case would merely elongate that portion of the cell to the right of the nucleus.

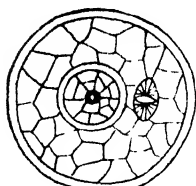


Fig. 19.

That would be so if, immediately the repulsive force begins to operate, the nucleus underwent no change. But it does change. The network of chromoplasm filaments of the resting nucleus becomes transformed into a sort of skein, into which the nuclear membrane and the nucleoli disappear.

The whole cell, with the exception of its exoplasm, appears, in fact, to be broken up, and its component parts to be marshalled into order by the centrosomes. But in what manner? If the broken-up nucleus was between the attraction spheres, as shown by Schäfer (Fig. 20), it is quite evident that a repulsive force alone would, so long as it continued to be exerted and for so long as the disintegrated nucleus had no polarity, maintain the substance between the attraction spheres at the same distance from each of them. It follows, logically, therefore, that if in the process of division one part of the cell cleaves to one attraction sphere, and the other part of the cell to the other attraction sphere, there must be a difference of polarity between them.

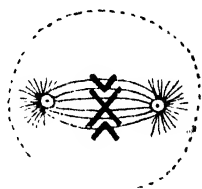


Fig. 20.

Suppose, for instance, the attraction spheres to be similarly electrified and to repel each other, so that they become farther apart, with a certain, non-electrified (or similarly electrified at lower tension) substance between

them. either the nucleus nor the nucleolus is non-electrified —of that I am sure—but during the early process of division the nuclear membrane and the nucleoli disappear or are merged in the skein. and, inferentially, lose polarity for the time being by loss of insulation and consequent diffusion. The moment, however, that insulation is even partially restored polarity would come into play ; and reference to physiological diagrams makes it clear that at this stage of division the two attraction spheres and the two parts of the nucleus are in close proximity, each with the other.

Assume that the attraction spheres and the nucleus are oppositely electrified, and we can understand why, in the first place, the single centrosome lies as near the nucleus as the structure of the cell permits ; secondly, there being an intervening space between the centrosomes, they should separate at that part, and in the process of the nucleus breaking down repel each other until they form poles at opposite ends of the cell. At that stage the nucleus would be in a condition of temporary disintegration or disarrangement, but as its insulation returned it would regain polarity, and, the pull being exactly equal, we can conceive one-half of it trending, by attraction, to the left and one-half to the right centrosome. Equilibrium would then be restored, and as the exoplasm completed the circle around each of the daughter nuclei, or rather around the protoplasm surrounding each daughter nucleus, the cell should divide by constriction.

I will endeavour to put it briefly. In its condition of *rest*, or, as I prefer to say, of *development*, I assume the centrosome and nucleus to be of opposite polarity. Upon duplication, the two centrosomes move to extreme ends of the cell. The moment the nucleus loses its membrane, and with it its insulation, it becomes similarly electrified, the chromosomes exercise a repulsive influence upon each

other under the control by the lines of force from the centrosomes, and, being in multiples of two, must divide in equal numbers at the equator. So soon, however, as the two sets of chromosomes regain insulation they again become oppositely electrified, are attracted by the centrosomes, and form two equal groups.

SEGMENTATION OF THE OVUM.

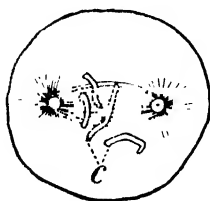
Usually, it is said, the two daughter cells are of the same size, but this is not so in the case of the ovum, which, before fertilisation, divides twice (by hetero- and homotypical mitosis respectively) "into two very unequal parts, the larger of which retains the designation of ovum, while the two small parts which become detached from it are known as the *polar bodies*. Further, in the formation of the second polar body a *reduction-division* occurs, and the nucleus of the ovum, after the polar bodies are extended, contains only one-half the number of chromosomes that it had previously—*e.g.*, twelve in place of the normal twenty-four in man, and two instead of four in *Ascaris Megalocephala* (var. *bivalvens*). Should fertilisation supervene, the chromosomes which are lacking are supplied by the male element (sperm-cell), the nucleus of which has also undergone, in the final cell-division by which it was produced, the process of reduction in the number of chromosomes to one-half the normal number. The two reduced nuclei—which are formed respectively from the remainder of the nucleus of the ovum after extrusion of the polar bodies, and from the head of the spermatozoon, which contains the nucleus of the sperm-cell—are known (within the ovum) as the *sperm* and *germ nuclei*, or the *male* and *female pronuclei*. When these blend, the ovum again contains a nucleus with the number of chromosomes normal to the species." (Schäfer.)

It will thus be seen that while the process of division

of the ovum is more complicated than that, for instance, of various kinds of somatic cells, it obeys the same law of alternat. repulsion and attraction.

This may be more readily comprehended by study of the fertilisation and first division of the ovum of the worm *Ascaris Megalocephala*, owing to the comparative simplicity of the structure and the smaller number of chromosomes.

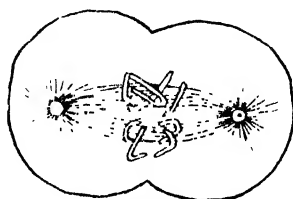
To put it, if I can, a little less technically than Schäfer, the ovum first discharges or extrudes from its interior two portions of its nucleus, which form globules upon the ovum and are called the polar bodies. These appear to play the same part as the centrosomes and attraction spheres in ordinary mitosis, and, disregarding for the moment the fusion of the male and female pronuclei, the penultimate stages of segmentation of the ovum, as shown by Schäfer, differ in no important respect from those of mitotic division. Those stages are illustrated in the following manner :—



A. Fig. 21.

Ascaris Megalocephala.

A.—Mingling and splitting of the four chromosomes (*c*); the achromatic spindle is fully developed, but division of the cytoplasm has not yet commenced.



B. Fig. 22.

B.—Separation (towards the poles of the spindle) of the halves of the split chromosomes, and commencing division of the cytoplasm. Each of the daughter cells now has four chromosomes; two of these have been derived from the ovum nucleus, two from the spermatozoon nucleus.

The extrusion of the polar bodies may be readily understood. We know that (1) like electricities repel one another, (2) unlike electricities attract one another, and

(3) the force of attraction or repulsion varies inversely as the square of the distance between the two electrified bodies, and directly as the amount of the charge of the two bodies.

We are also aware that one of the earliest changes to occur in mitosis and in segmentation is the breaking up of the nuclear membrane. Assume, then, that the nucleus is an electrified body and that those portions of it which become the polar bodies are the first to detach themselves or be detached from it, and the process of extrusion (by repulsion) becomes clear. We are also entitled to believe that their amount of charge is exactly equal, and have seen that the chromosomes are always in multiples of two. That being so, the latter should, upon regaining some measure of their insulation, trend towards the polar bodies (by attraction) in two groups of equal numbers.

In plant life sexual reproduction is first found in the form of conjugation, as in *mucor* and *spirogyra*, where the male and female elements are similar in shape and size. They are simple *cells*, and fuse together to produce a *zygospore*.

“*Fucus* exhibits sexual production alone, and that in a very typical manner. Male and female *organs*, in this case trichomes, are present, which produce respectively small motile *male cells*, spermatozoids, and passive, relatively large *female cells*, the oöospheres. One male cell fuses with each female cell, which is now *fertilised*, and can develop into a new plant.” (Davis.)

The phenomena presented by sexual or asexual reproduction appear to be common to all forms of animal and vegetable life, from the lowest to the highest. The presence of nuclei has been demonstrated in the vegetative and reproductive parts of fungi belonging to widely separated orders, and *Schizomycetes* are of the class of fungi and require organic matter as food; in diatomaceæ and in protozoa; and I have little doubt that if a sufficiently high

power could be used bacteria would be seen to be mostly multicellular organisms which, by division and subdivision, proliferate themselves in much the same way as some of the species of confervoideæ.

“In all probability,” remarks Masee, in *The Evolution of Plant Life*, “nuclei in a primitive state of differentiation are present in all plant cells. The exact function of the nucleus is not known, but judging from its almost universal occurrence, and its behaviour in connection with the formation of new cells, it must be supposed to perform some important function.”

With that view we must all be in agreement. Without the nucleus cell-reproduction could not occur.

If that is so, however, and we suppose bacteria to multiply themselves by the exercise of some electro-chemical function, we must draw a line of demarcation between aërobic and anaërobic micro-organisms. The former need only contain some substance electro-positive to oxygen for electrical action to occur, whereas the latter should be self-contained; that is to say, they should be provided with both positive and negative materials, requiring only suitable liquid to excite them.

Those who doubt the existence of a network in protoplasm would do well to examine, for example, the naked protoplasm of a myxogaster (a yellow-coloured saprophyte, generally met with on decaying wood), and the structure of a grain of wheat and of rice, with special regard to the arrangement and insulation of the starch cells. The same phenomenon, in a modified form, will be observed; and, if vegetable and animal physiology were always studied together many other doubts and perplexities might be resolved.

I am not concerned with enzyme action in its chemical aspect, but certain facts in connection with it are not without significance. The action is intracellular; a

of temperature has much the same effect upon enzymes as it has upon the velocity of the nerve impulse, they die at much the same temperature as protoplasm, and their activity is checked or destroyed by many of the chemical substances, such as strong acids and alkalis which check or destroy amoebic movement. This proves nothing, but it opens the door to the suggestion that enzyme action, instead of being wholly chemical, may be in some measure electrical.

The best description of cell-division in plants is given by Professor Vines in his *Text-book of Botany*. He says: "The indirect division of the nucleus presents a series of remarkable phenomena which are collectively designated by the term *karyokinesis*. Beginning with the nucleus in the resting-state, the first fact indicating the imminence of nuclear division is that the two centrospheres" (centrosomes) "separate and take up positions on opposite sides of the nucleus, thus indicating the plane in which the nuclear division is to take place, *viz.*, at right angles to a straight line joining the centrospheres: the change of position of the centrospheres is doubtless effected by the kinoplasm in which they lie. Changes are now perceptible in the nucleus itself. The fibrillar network contracts and becomes more dense, and breaks into distinct fibrils (*chromosomes*) consisting now of broad discs of chromatin with narrower intervening discs of linin; the tangle of the somewhat V-shaped fibrils becomes looser as they separate and move towards the surface of the nucleus. At this stage the so-called nuclear membrane loses its definiteness, the kinoplasm entering the nucleus without, however, displacing the proper ground-substance of the nucleus. The kinoplasm forms a number of threads, extending from one centrosphere to the other, constituting the *kinoplasmic spindle*" (achromatic spindle), "of which the centrospheres are the two poles. Along these threads the fibrils move

till they reach the equatorial plane of the spindle, where they constitute the *nuclear disc*, and are so placed that their free ends point to either one pole or the other. Whilst these changes have been going on, the nucleoli have disappeared, being diffused in the nuclear ground-substance. The fibrils now undergo longitudinal splitting into two, and then the nuclear disc separates into two halves, in such a way that one of each pair of fibrils produced by the splitting of each primary fibril goes to each half. The fibrils constituting each half of the nuclear disc now move towards the corresponding pole along the spindle-threads, changing their position as they go, so that when they reach the pole their free ends point towards the equatorial plane. On reaching the pole, each group of fibrils constitutes a new nucleus; it becomes invested by a membrane, nucleoli reappear, and the fibrils resume the form and structure of the resting nucleus. The two nuclei are now completely formed, and are still connected by kinesisplasmic spindle-threads" (as in Fig. 17). "If no cell-division is immediately to take place, no further change occurs beyond the disappearance of the threads," and this, it will be noted, is the stage immediately preceding division in ordinary mitosis.

It is interesting to compare this account of vegetable cell-reproduction with that given by Schäfer of mitotic division of the animal cell. The wording is different, but the processes appear to be identical.

CHAPTER VIII

ANIMAL MAGNETISM

FOR more than a century we have heard of "Animal Magnetism," and even some modern scientific men—Professor Rosenthal amongst the number—are inclined to attribute certain vital phenomena to magnetic influences contained in the body.

The temptation to do so is great because some points of resemblance may be found, but the view is a fallacious one, as I will endeavour to show.

Inasmuch as we do not know what the force called magnetism is, I do not propose to discuss it further than is necessary. In the course of nearly forty years of research work I have not been able to find any evidence of its existence in the human body. Superficially, however,

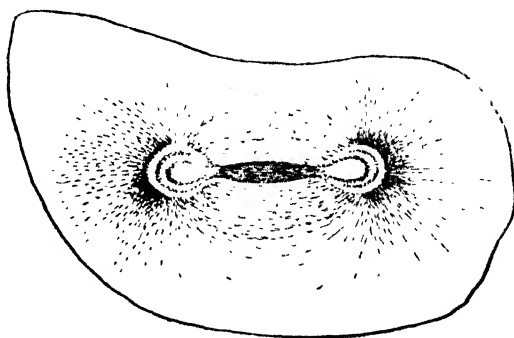


Fig. 23.

certain phenomena may appear to be due to magnetic control.

As instances of this we may take mitotic division and

the segmentation of the ovum, which, as we have seen, permits of another and more reasonable explanation.

In a work called *The Evolution of Sex*, by Geddes and Thomson, the illustration on preceding page is given of cell-division, suggesting the internal disruptions and rearrangements of the nucleus and protoplasm.

Let us compare that with the lines of force of a bar magnet.

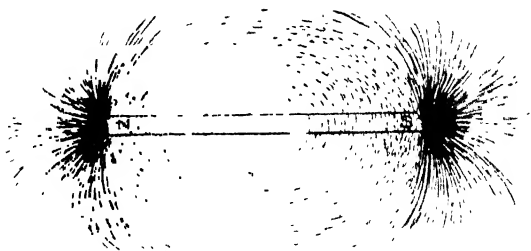


Fig. 24.

There is a quite remarkable similarity. We will, however, instead of one, take two bar magnets and arrange them thus and with this result:—



Fig. 25.

They would repel each other; the space between the two might be called the achromatic spindle and the magnets themselves the centrosomes. But we should have precisely the same result if for the magnets we substituted two similarly electrified bodies.

All the body phenomena can be readily and, I believe, correctly explained in the same way, by the law of electrical attraction and repulsion, both as regards intra- and extra-cellular control, and to the best of my knowledge there is no such thing as animal magnetism.

CHAPTER IX

SOME EVIDENCES OF THE LAW

ANIMAL



Fig. 26.

One of the phases of the nuclear chromatin filaments in the process of ordinary mitosis of the somatic cell. (*Schäfer.*)

VEGETABLE

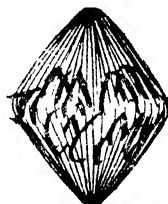


Fig. 27.

One of the changes of the cell-nucleus during division (*Allium odorum*). (*After Sachs.*)



Fig. 28.

Epithelium-cells of salamandra larva in different phases of division by mitosis. (*Schäfer.*)



Fig. 29.

Changes in the cell-nucleus during the division of the mother-cell of a stoma of *Iris pumila*. (*After Strasburger.*)

ANIMAL

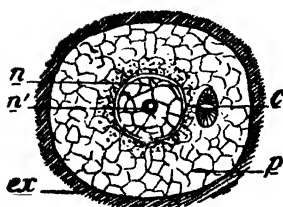


Fig. 30.

Diagram of a cell.—*p*, protoplasm; *n*, nucleus; *n¹*, nucleolus; *c*, double centrosome; *ex*, exoplasm. (After Schäfer.)

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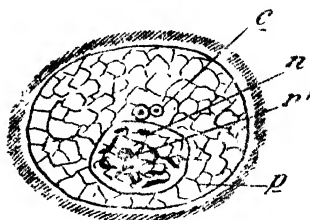


Fig. 31.

Young pollen-grain of *Lilium Martagon*, showing, *c*, double centrosphere; *n*, resting nucleus; *n¹*, nucleolus; *p*, protoplasm. (After Guignard.)

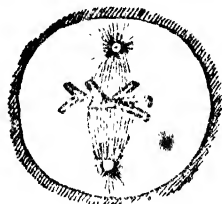


Fig. 32.

Diagram showing a change in the centrosomes and nucleus of a cell in the process of mitotic division. The nucleus is supposed to have four chromosomes. (After Schäfer.)

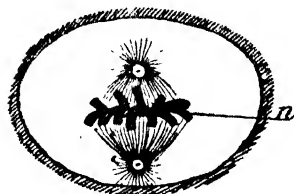


Fig. 33.

Germinating pollen-grain of *Lilium Martagon* with dividing nucleus: the kinoplasmic spindle is formed with a centrosphere at each pole; *n* is the nuclear disc formed by the chromosomes. (After Guignard.)

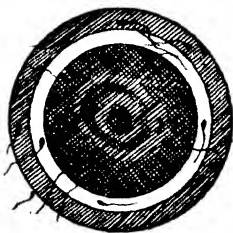


Fig. 34.

Fertilisation of the ovum by the spermatozoon (of a mammal). (After Haeckel.)



Fig. 35.

Oösphere, with spermatozooids. (After Strasburger.)

The foregoing may be considered as direct evidences of the universality of the law which governs all living things. The examples I am about to cite cannot be said to fall, without question, into this category, because while the structures exhibit a striking resemblance, the organs are not in all cases designed for the same purpose or function. A little reflection, however, will show that, so far as structure is concerned, it differs only in detail, in more or less perfection of finish or development; the underlying principle is there. Let us call them coincidences for the time being, and trust to future investigation to link them in some measure more closely together. It may here be said that only from the "living" can any reversal of sign, implying an electrical system, be obtained. In the "non-living" there is no difference of potential unless introduced by some exterior vehicle of energy.

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Fig. 36.

Ganglion cell with nerve process (human).

VEGETABLE



Fig. 37.

Original spore of *Vaucheria sessilis*. (After Sachs.)

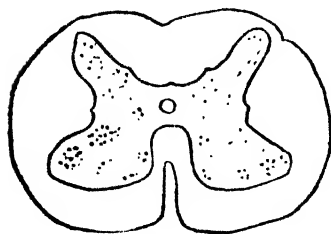


Fig. 38.

Section of spinal cord (human). (After Schäfer.)

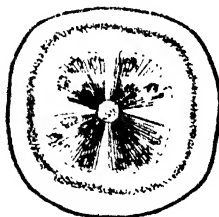


Fig. 39.

Diagrammatic sketch of transverse section through portion of root of *Phaseolus multiflorus*. (After Sachs.)

ANIMAL

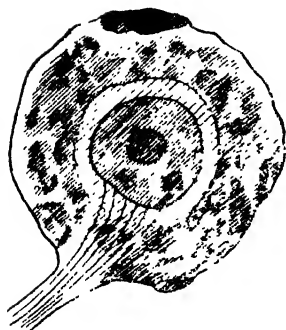


Fig. 40.

Unipolar cell from spinal ganglion of rabbit. (After Schäfer.)

VEGETABLE

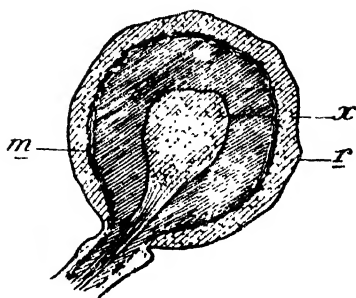


Fig. 41.

Usnea barbata. Transverse section of a branch: *r*, epidermal layer; *m*, fundamental tissue; *x*, axial strand. (After Sachs.)

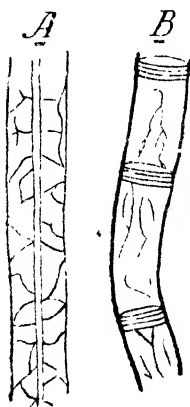


Fig. 42.

A. Spiral and reticular fibrils in the sheath of a nerve-fibre.

B. Reticular appearance in the medullary sheath of a nerve-fibre. (Schäfer.)

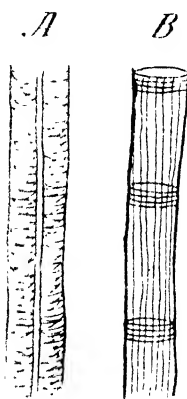


Fig. 43.

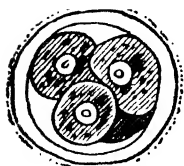
A. Cells from a leaf of *Hoya carnosa*.

A. External view of the side where the annular striae cross.

B. Portion of an annular vessel from the fibro-vascular bundle of *Zea Mays*. (After Sachs.)

The main differences between the two sets of figures appear to be due to the absence of blood-vessels in the vegetable sections; although there seems to be a provision for the circulation of sap in the latter.

ANIMAL



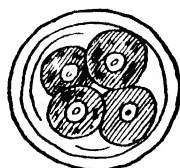
A

Fig. 44.

Formation of blastoderm in rabbit by division of ovum into a number of cells.

A. During formation of "mulberry mass." (Schäfer.)

VEGETABLE



B

Fig. 45.

Athra rosea; division of the pollen mother-cells.

B. A stage thereof. (After Sachs.)

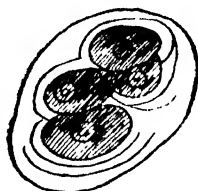


Fig. 46.

A group of cartilage-cells showing the capsular outlines in the matrix surrounding the group. (Ranvier.)

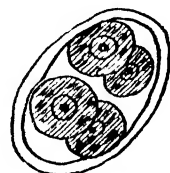


Fig. 47.

The same, in a slightly different form, as the above.

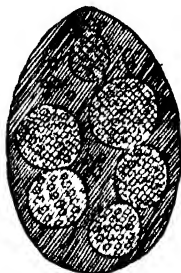


Fig. 48.

Part of a transverse section of the sciatic nerve of a cat.

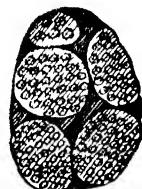


Fig. 49.

A parenchyma cell from the cotyledon of *Phaseolus multiflorus*. (After Sachs.)

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Fig. 50.

Two white fibro-cartilage cells from an intervertebral disk (human). (Schäfer.)

VEGETABLE



Fig. 51.

Two thickened cells from the cortical tissue of the stem of *Lycopodium chamaecyparissus*. (Sachs.)

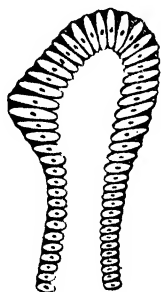


Fig. 52.

From a section through a salivary gland (human). (After Noble Smith.)

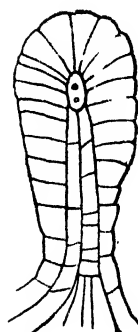


Fig. 53.

Glandular collector from a stipule of *Viola tricolor*. (After Strasburger.)



Fig. 54.

Muscular fibre-cell from the small intestine (human). (After Schäfer.)

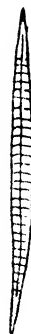


Fig. 55.

A sclerenchymatous fibre (vegetable). (After Strasburger.)

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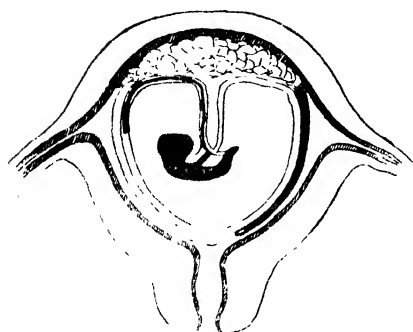


Fig. 56.

Diagrammatic frontal section of the pregnant human womb. (After Haeckel.)

VEGETABLE

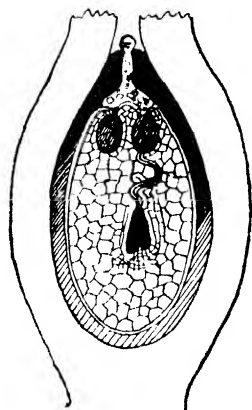


Fig. 57.

Ovule of a gymnosperm in longitudinal section. (After Sachs.)

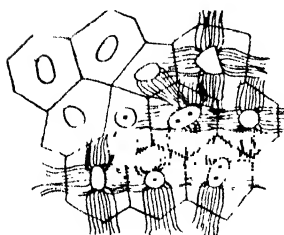


Fig. 58.

Epithelium-cells of Descemet's membrane. (After Smirnov and Nußl.) (Schäfer.)

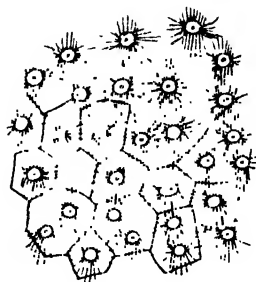


Fig. 59.

Portion of the peripheral protoplasm of the embryo-sac of *Reseda odorata*. (After Strasburger.)

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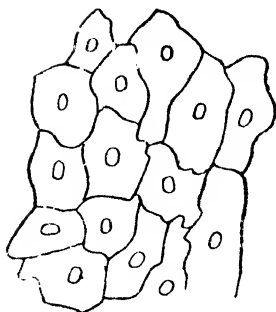


Fig. 60.

Endothelium of a serous membrane (human). (After Schafer.)

VEGETABLE

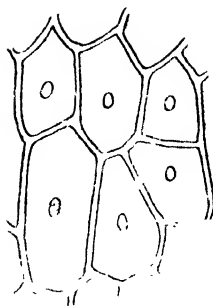


Fig. 61.

Cells from a tendril of *Cucurbita pepo*. (After Strasburger.)

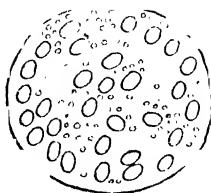


Fig. 62.

Section across a nerve bundle in the second thoracic anterior root of the dog. (After Gaskell.)

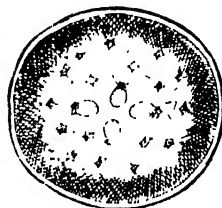


Fig. 63.

Transverse section through a young internode of the shoot axis of *Tradescantia albiflora*. (After De Bary.)

ANIMAL

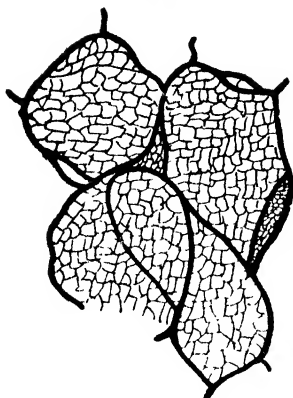


Fig. 64.

Network of capillary vessels of the air-cells of the horse's lung. (After Frey.)

VEGETABLE

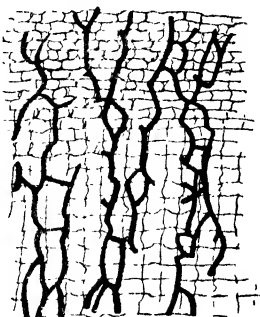


Fig. 65.

Laticiferous vessels from a section through the root of *Scorzonera hispanica*. (After Sachs.)

LATICIFEROUS VESSELS.

The resemblance of laticiferous to blood-vessels is remarked by Sachs. He says: "The laticiferous vessels themselves are always so narrow that they can never be seen on a transverse section of the organ with the unaided eye. The microscope, however, shows that they may be of very different diameter in the same plant. In the roots, shoot-axes, and nerves of the leaves, run thicker tubes, from which thinner and yet thinner ones arise. The substance of the walls of the tubes always consists of soft cellulose, sometimes capable of swelling; they are never lignified, suberised, or otherwise essentially altered by infiltration. One of the most prominent characteristics of the laticiferous vessels is their continuity throughout the whole plant, or at any rate over wide areas. This may obviously, even if not in every point, be closely compared with the vascular system of an animal. . . .

If it were possible by any means to destroy all the other tissues of such a plant as a large *Euphorbia* or *Asclepias*, the entire form of the plant would still be preserved as a mass of very fine threads of various thickness, representing the ramifications of the original latex-cells; just as the injected vascular system of a vertebrate animal after the removal of all other tissue allows the whole organisation of the body to be recognised. . . . The laticiferous vessels contain two essentially different groups of substances: those which are again utilised in metabolism (proteids, carbo-hydrates, fats, ferments), and those which must be regarded as excreta useless in metabolism (resins, gums, alkaloids, etc.).

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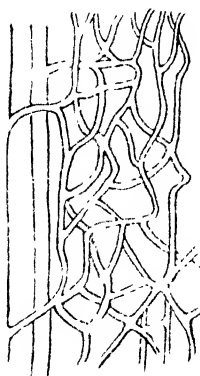


Fig. 66.

Injected blood-vessels of a human muscle. (After Landois and Stirling.) (Kolliker.)

VEGETABLE

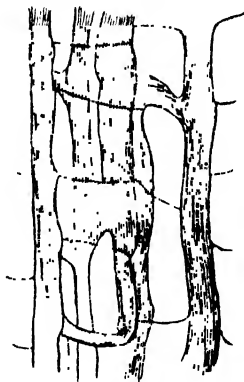


Fig. 67.

Section from *Scorzonera hispanica* showing reticulately united latex vessels. (After Strasburger.)

“The green vegetables are particularly rich in salts, which resemble the salts of the blood; thus, dry salad is said to contain twenty-three per cent. of salts, which closely resemble the salts of the blood.”

Given the necessary patience, I have no doubt that

many other examples could be found, but the foregoing should be in themselves sufficient to establish the point I have been endeavouring to make.

Unfortunately it is not always possible to find parallel illustrations, but I may take the opportunity afforded by this chapter to give the views of some authorities upon points of resemblance between animal and vegetable organisms. In *Vegetable Physiology*, by J. R. Green, F.R.S., I find the following: "If we turn to the reaction of the leaf of the *Dionæa* to contact, we find that the whole leaf may be somewhat roughly handled without closing, so long as no contact is made with the hairs, three in number, which arise on a particular portion of the blade. So soon, however, as one of these is touched, the leaf closes.

"It is impossible to avoid the conclusion that we have to do in these instances, which are only representative ones, with a localisation of sensitiveness, or the differentiation of sense-organs. . . . The power of sight is very complete in the higher animals . . . but in the lower animals it becomes less and less perfect, till in some it goes probably little further than the power of appreciating light. This power we have seen to be possessed by certain parts of the young seedlings of various plants in a very high degree, and by other organs to a less extent. The sense of touch may be compared with the power of responding to the stimulus of contact shown by tendrils and by the tips of roots; the muscular sense, or power of appreciating weight, is perhaps comparable to the property of responding to the attraction of gravitation, while the chemotactic behaviour of certain organisms suggests a rudimentary power of taste or smell, or both. . . . If we turn to a second feature of the nervous system, we find that the motor mechanism of the plant seems at first to be entirely different from that of the animal. Closer consideration, however, lessens the difference considerably. The motor

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mechanism of an animal is very largely either muscular or glandular. The contractile power is but little developed in vegetable protoplasm, and when present it seems to be rather passive than active, to produce frequently recoil rather than true contraction. Still, the latter is not entirely absent. . . Though the power of contraction is comparatively seldom found, it has its representative in the power which vegetable protoplasm possesses of resisting or assisting the transit of water. . . . The main requirement of most animals is freedom of locomotion or rapid assumption by the body of new positions. The most important duty of the plant is the regulation of the water supply upon which its constituent protoplasts are so dependent." This is chiefly, if not entirely, accomplished by means of the stomata upon the under surface of the leaves, which open or close in accordance with the requirements of the plant. Three of these are shown in the following figure :—

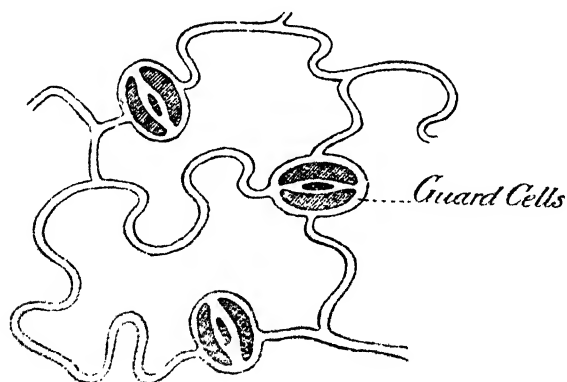


Fig. 68.

Surface view of part of the under surface of a leaf, showing three stomata in different stages of opening and closing. (After Green.)

"The effects of stimulation may be seen in glandular organs in plants as well as animals. Both *Drosera* and

Dionæa are excited by contact to pour out on to the surface of their leaves acid digestive secretions, which are the result of changes in the activity of the gland-cells.

"The conduction of the stimuli received is due in animals to the existence of differentiated nerves. The way in which it is carried out in plants has been much debated, but since the discovery of the continuity of the protoplasm through the cell-walls there is little doubt that we have here a similar mechanism. . . . Though there is no particular differentiation of an anatomical character in any of the sense-organs of a plant, there is nevertheless a differentiation of a physiological nature in the direction of sensitiveness, which will equal if not surpass the powers of the sense-organs of an animal. The tendril of *Passiflora* appreciates and responds to a pressure which cannot be detected by even the human tongue; the seedlings of *Phalaris* readily obey the stimulus of an amount of light which is hardly perceptible to the human eye. Many plants readily detect and respond to the ultra-violet rays of the spectrum, which are utterly invisible to man."

In his thirty-fourth lecture, *General Considerations of Irritability*,* Sachs said: "Returning from these general considerations to definite comparisons between the animal and the plant, I would make special mention of that exceedingly remarkable phenomenon in animal life, termed by its great discoverer, Johannes Müller, the specific energies of the sensory nerves. As is well known, we understand by this fact that for instance the optic nerve responds to any given excitation whatever with the sensation of light: true, this sensation is as a rule called forth by the vibrations of the luminiferous ether, but even electric currents or mere concussion or diseased conditions impel the optic nerve to the sensation of light. In the

* *The Physiology of Plants.*

same way the auditory nerve is impelled to the perception of sound, not merely by waves of sound, but by every change which affects it, and similarly with the remaining organs of sense.

“ Now I pointed out years ago that even the organs of plants are provided with similar specific energies. Irritable organs in plants are, indeed, like the sense-organs of animals, sensitive to a definite category of stimuli, but they can very often be affected by other stimuli also, and in this case the stimulation is always the same. This appears most distinctly, for example, in the case of growing internodes and leaves. If they are illuminated from one side they become curved, and if brought out of their normal position they are caused to make exactly similar curvatures: the one mode possible for responding to any stimulus whatever is simply this curving. The matter only obtains its full significance by the fact that every individual plant-organ responds to the influence of light as well as to that of gravitation in a manner specifically peculiar to it, and it is upon this that the anisotropy of the parts of plants depends. No less clear is the specific energy of tendrils. . . . The identity of the effect of stimulation in cases where totally different stimuli act on the growing root-tips is particularly striking. . . . The organ possesses only one mode of responding to stimuli of the most various kinds. . . . The organism itself is only the machine, consisting of various parts, and which must be set in motion by the action of external forces: it depends upon its structure what effects these external forces produce in it.

“ It would betray a very low level of scientific culture to see in this comparison a degradation of the organism, since in a machine, although only constructed by human hands, there lies the result of the most profound and careful thought and high intelligence, so far as its structure is

concerned, and in it there subsequently become effective the same forces of Nature which in other combinations constitute the vital forces of an organ. . . . We are warranted in regarding the so-called spontaneous or independent periodic movements " (in plants) " as phenomena of irritability, just as animal physiologists place the periodic pulsations of the heart in the series of phenomena of animal irritability. . . . I have repeatedly had cause to refer to certain resemblances between the phenomena of irritability in the vegetable kingdom and those of the animal body, thus touching a province of investigation which has hitherto been far too little cultivated."

Consideration of enzyme action does not come within the scope of these studies, but it appears to be common to both animal and plant. According to Vines the chief kinds of enzymes which have been found in plants are :—

- " (1) Those which act on carbohydrates, converting the more complex and less soluble carbohydrates into others of simpler composition and greater solubility.
- " (2) Those which act on fats, decomposing them into glycerine and fatty acid.
- " (3) Those that act on glucosides, glucose being a constant product.
- " (4) Those that act on the more complex and less soluble proteids, converting them into others which are more soluble and probably less complex, or decomposing them into non-proteid nitrogenous substances (amides, etc.)."

As regards a comparison of fats in animals and plants, Sachs showed as long ago as 1858 that in the germination of seeds containing fat, a transference of the fatty oils from the cotyledons, or from the endosperm into the growing parts of the seedling, appears to take place, and this was confirmed by chemical analysis by Peters. In his twenty-first

lecture Sachs said: "It appears that the fats can pass through the closed tissue-cells as such; though of course the greater part of them is transformed into starch and sugar for transport and use. Similar phenomena with respect to fats occur moreover in the animal body, where the fats entering into the stomach are in the first place emulsified by the secretion from the pancreas, that is, they become converted into exceedingly fine drops and then saponified. . . . The presence of fats in the seedling can only be explained by assuming that glycerine and fatty acids travel from cell to cell, and are continually becoming reunited for the formation of fat."

In the case of plants in dry climates, or so situated that, for any reason, transpiration from their outer surfaces must be diminished, they are characterised by the greatly thickened and cuticularised walls of their epidermal cells. Deposits of wax are also present in the cutinised layers of the epidermis, and consequently water will flow off from the epidermis without wetting it. The wax is sometimes spread over the surface of the cuticle as a wax covering. This is the case in most fruits, where, as is so noticeable in plums, it forms the so-called bloom. (Strasburger.)

There can, I think, be no doubt that the main purpose underlying the provision of the wax covering of fruits is the preservation of their absolute insulation, and one can be sure, even without examination, that where the outer skin or rind of a fruit is of comparatively delicate texture—as of the plum—while the fruit itself is juicy and highly conductive, the protective "bloom" will be found to be most abundantly provided.

There is at least some analogy between this and the sebaceous secretion of the human epidermis; both are apparently designed for the performance of the same function.

In cases where wax is absent or in greatly diminished

quantity, protection of a similar nature is afforded by resin, or by a covering or capsule of a fibrous character, as, for instance, in the leaf of the ivy and the capsules of various beans and seeds, etc.

In regard to the comparison by Sachs of the laticiferous vessels of plants to blood-vessels of vertebrate animals, he instanced the fact that when a milky stem is cut not only the low cut surface of the apical portion but the upper one of the root-stock also extrudes the latex. Besides, the laticiferous vessels are extremely narrow capillary tubes, the normal terminations of which in the buds, leaves, and root-apices are closed. How, he asked, could fluid flow out at all on cutting such capillaries closed at the ends unless the fluid was under pressure? "When we wound

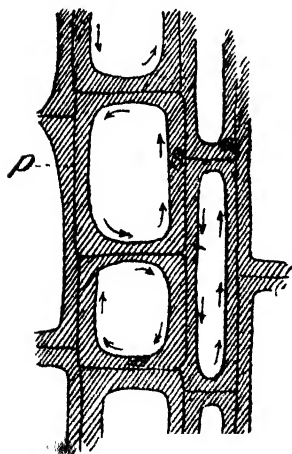


Fig. 69.

Cells from the leaf of *Elodea* ;
p, protoplasm.

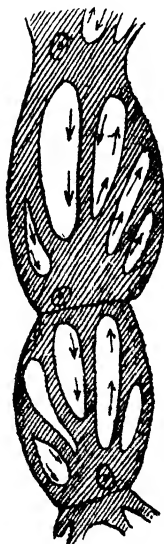


Fig. 70.

Two cells from a staminal hair
of *Tradescantia*.

ourselves the blood does not simply flow out, it is driven out."

In regard to the movement of protoplasm in plants some interesting facts are given by Green. In cells from the leaves of *Elodea* and the staminal hairs of *Tradescantia*, to take two examples, the current appears to *circulate*, as will be seen from the two figures on the preceding page.

The same author has much to say upon the subject of *rhythmic* movement in plants. "If we look back," he writes, "to the behaviour of the contractile vacuole of *chlamydomonas*, we are struck by the fact that its pulsations occur with a certain definite intermittence so long as they are not interfered with by external conditions. The vacuole dilates slowly, reaches a certain size, and suddenly disappears; then is gradually formed again, and the series of events is repeated. This regular intermittence constitutes what is often spoken of as *rhythm*. The rhythm which is so easily seen in the case of pulsating vacuoles is characteristic also of those less obvious changes in protoplasmic motility which lead to the variations of turgidity in different organs, particularly in those which are growing. During the growth in length of a symmetrical organ, such as a stem or root, the apex points successively to all points of the compass. This is the result of a rhythmic variation of the turgidity of the cells of the cortex. If we consider a longitudinal band of such cells, we find that at a certain moment the cells are at their point of maximum turgidity, and the growing apex is made to bend over in a direction diametrically opposite to this band. The turgidity of this band then gradually declines to a minimum, and again increases slowly to a maximum. If we conceive of the circumference of the organ as divided into a number of such bands, we can gain an idea of the changes in turgidity which cause the circumnutation. Each band is in a particular phase of its rhythm at any given moment, and the successive bands follow one another through the phases of their rhythm in orderly sequence, so that when one is at

STUDIES IN ELECTRO-PHYSIOLOGY

its maximum, another diametrically opposite to it is at its minimum. The phases of maximum and minimum turgidity thus pass rhythmically round the organ, and the apex is consequently compelled to describe a spiral line as it grows. . . . It is not infrequent for the rhythmic change in the turgescence to affect only two sides . . . its changes will thus resemble those of a flattened organ which can only be made to oscillate backwards and forwards."

Until I read Green's *Vegetable Physiology* I was not aware that this rhythmicality of movement had been observed, but the subject is to me one of peculiar interest. It so happens that some years ago I carried out a series of galvanometric tests with plants—invariably at night—and took note of phenomena which, in their electrical aspect, were suggestive of rhythmic inspiration and respiration.

The paralysis or destruction of protoplasmic movement in both animal and vegetable bodies appears to occur from identical causes, as will be seen on reference to the Study of Amœboid Movement.

One question which has engaged my attention is: Can there be any analogy between the propagation of impulse in mammal and plant? Though the possession of nerves is denied to the latter by some authorities, there is little if any doubt that they are present in a rudimentary form, and in such case the propagation of stimuli should, logically, be possible.

Green remarks: "In considering broadly the result of stimulation" (of plants) "we must notice at the outset that it provokes a *purposeful* response. The living substance appears to have a definite aim."

"If any one of the small leaflets of a leaf, on a shoot of *Mimosa* with five or six leaves, is stimulated by means of the hot focus of a burning glass, all the other leaflets of the same leaf gradually fold together, and after a time the

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large motile organ at the base of the main petiole also becomes bent, and again after a few seconds the stimulation extends to the nearest neighbouring leaf, then to the succeeding one, and so on, till at last all the leaves of the shoot have made the movement." (Sachs.)

The rate of propagation of stimuli in the plant, as compared with man, is, of course, relatively very slow. That is, if we regard it as a purely physical process in the sense that when a stretched string is jerked at one point the whole string vibrates. But if we take the rate of conduction of a feeble electrical stimulus, I do not think it will be found to differ materially from the rate of conduction in a human nerve.

CHAPTER X

AMÆBOID MOVEMENT

“THE protoplasm tends during life to exhibit movements which are apparently spontaneous, and when the cell is uninclosed by a membrane a change in the shape, or even in the position of the cell, may be thereby produced.” (Schäfer.)

One of the constituents of cell-protoplasm is called nucleo-protein, and the normal supply of iron to the body is contained in the nucleo-proteins of plant and animal cells.

A cell possesses the power of breathing, *i.e.*, taking in oxygen.

“There is no doubt that protoplasmic movement is essentially the same thing in both animal and vegetable cells. But in vegetable cells the cell-wall obliges the movement to occur in the interior.” (Halliburton, 1915.)

What is the nature of that movement? I learn from the same source that if a living amœba is watched for a minute or two, an irregular projection is seen to be gradually thrust out from the main body and retracted, a second mass is then protruded in another direction, and gradually the whole protoplasmic substance is, as it were, drawn into it. The amœba thus comes to occupy a new position, and when this is repeated several times we have locomotion in a definite direction, together with a continual change of form. (Halliburton, 1915.)

Is it not possible to explain this movement by the electrical law of attraction and repulsion? Iron, as I have

remarked elsewhere, is fifth in the scale of electro-positives and oxygen at the bottom of the list of electro-negatives; and providing that osmosis can take place and there is an exciting solution, such electrical action may very well occur.

Upon the assumption that it does so occur let us see how the movements of the amoeba are affected by stimuli.

“(1) CHANGES OF TEMPERATURE.—Moderate heat acts as a stimulant. The movement stops when the temperature is lowered near the freezing-point or raised above 45° C.

“(2) CHEMICAL STIMULI.—Distilled water first stimulates, then stops amoeboid movement. In some cases protoplasm can be almost entirely dried up, but remains capable of renewing its movement when again moistened. Dilute salt solution and very dilute alkalies stimulate the movements temporarily. Acids or strong alkalies permanently stop the movements; ether, chloroform . . . also stop it for a time.

“Movement is suspended in an atmosphere of hydrogen or carbonic acid, and resumed on the admission of air or oxygen; complete withdrawal of oxygen will after a time kill protoplasm.

“(3) ELECTRICAL.—Weak currents stimulate the movement, while strong currents cause the cells to assume a spherical form and to become motionless.”

I will repeat, but paraphrase, the foregoing—

(1) *Change of Temperature*.—Moderate heat acts as a stimulant by lowering internal resistance. The movement stops when the temperature is lowered near the freezing point because of the enormous increase of internal resistance so created, and as protoplasm dies at 45° C. (or thereabouts), that temperature would naturally bring about cessation of movement by killing the protoplasm.

(2) *Chemical Stimuli*.—Distilled water, regarded as a foreign substance or fluid, may bring about a momentary

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disturbance, but by reason of its high resistance would tend to stop movement after a short time. In some cases protoplasm can be almost entirely dried up, but remains capable of renewing its movement when again moistened. Its electrical activity—and especially capacity—is dependent upon the presence of conductive moisture, and when not so moistened it would become inert. That dilute salt solution and very dilute alkalies stimulate the movements temporarily by lowering internal resistance is what might reasonably be expected. As, however, there would be some alteration of the chemical composition of the cell-contents the efficiency of the cell would no doubt be ultimately impaired. Obviously also acids or strong alkalies would permanently stop the movements by causing diffusion; ether and chloroform, as is well known, interfere with conduction, and, moreover, I am quite sure that the least trace of tincture of nux vomica would be fatal.*

That movement is suspended in an atmosphere of hydrogen or carbonic acid calls for no explanation, but the fact that complete withdrawal of oxygen will, after a time, kill protoplasm is a strong argument in favour of the hypothesis that movement is due to electrical action.

(8) *Electrical*.—Weak currents, by supplementing the natural energy of the cell, stimulate the movement, but strong currents paralyse the protoplasm, or by disrupting its electrical structure cause it to revert to its original shape when at rest.

In considering the theoretical solution I have offered of amœboid movement, it is as well to bear in mind that although the chemical composition of the dead amœba can be resolved by analysis, such is not the case with the living amœba, in which, in all probability, these chemical substances are represented by their groups of ions. If that is so it can readily be imagined that, with a constant intake of

* See experiment with begonia (p. 159).

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oxygen, a complex electro-chemical action between it and the iron in the cell may be set up, which by attraction and repulsion gives rise to the observed phenomena.

In this connection reference may usefully be made to the experiments of Ampère. He proved by means of movable wires that attraction was shown when the currents ran in the same direction and repulsion when in opposite directions; also that when two finite currents are inclined to each other without crossing, they attract when both run towards or both run away from the common apex, but repel when one runs towards and the other away from the apex.

When the currents are in the same direction, the surfaces oppositely electrified will be directly opposed, and therefore attraction ensues. If the currents are in opposite directions the surfaces similarly electrified will oppose, and therefore repel each other.

In protoplasm there are many possible "surfaces" in the form of more or less vertical divisions of the cell.

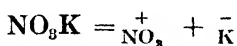
Supposing amoeboid movement to be due to either attraction or repulsion, or both, causing the irregular projections, we can understand that upon one current momentarily ceasing to flow or diminishing in intensity such projection would, wholly or partially, be withdrawn, because it had its origin in the first instance in a force, and upon that force being no longer operative or altering in intensity a change of form would take place.

It will be remembered that early in the last century Davy passed a current through a solution of potash, and finding that the potassium went to one of the poles and the oxygen to the other, concluded that the two elements of a compound are charged with different electricities, which are neutralised on combination. That is the view now held—after so long, and so lamentable a loss of time.

"The actual theory of ionisation may be summed up

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in the following statement, which does but repeat exactly the ideas of Faraday : Bodies are composed of elements or ions charged, some with positive, others with negative electricity, and united at first in the neutral state. Under the influence of the battery current, the neutral molecule dissociates into positive and negative elements, which go to the poles of contrary names. The decomposition of a neutral salt may be represented by such an equation as :



“ When an ion leaves a solution in order to precipitate itself at an electrode charged with electricity of contrary sign—by reason of the attraction exercised between two opposite electric charges—it then becomes neutralised, which means that it receives from the electrode a charge exactly equal but of contrary sign to that which it before possessed.

“ Adopting the theoretical ideas put forward by Clausius, Arrhenius recognised that an electric current was in no way necessary to produce the dissociation of compounds into ions. In dilute solutions the bodies dissolved must be separated into ions by the mere fact of solution. When the electrodes of a battery are plunged into such solution, the ions must simply be attracted by them—the positive ions by the negative pole, and the negative ion by the positive pole.” (Le Bon.)

According to Czapec, in any solution the degree of this dissociation depends on the nature of the salt, the temperature of the solution and its strength. Acids and alkalies when diluted to one milligramme in one litre of water are entirely broken up into ions and cease to exist as acids and salts. Halliburton tells us that the proportion of inorganic salts in the blood plasma is 8.55 in 1,000, or approximately 0.9 per cent. ; but that is the sum total of *all* the salts.

I do not know what the percentage of alkali in the cell-contents may be. In any case there must be a certain amount of electrolysis due to the body current and irrespective of intra-cellular action. In blood plasma sodium is present to the extent of about 0.334, potassium 0.082, and chlorine 0.864 per cent.

As regards rigor, or cessation of protoplasmic movement in plants, Sachs gives the following information:—

(1) Temporary cold-rigor occurs in the motile organs of *Mimosa pudica*, when the temperature remains for some hours below 15° C. The lower the temperature falls below 15° C. the more rapidly the rigor sets in.

(2) Temporary heat-rigor occurs in *Mimosa*, in moist air at 40° C. within one hour; in air at 45° C. within thirty minutes; in air at 49°-50° C. within a few minutes. The irritability returns after a few hours in air at a favourable temperature.

Rigor is also caused by the withdrawal of oxygen; when brought into the air the plant again becomes motile. Irritability disappears in hydrogen and nitrogen in carbon dioxide and ammonia, but returns on free exposure to air. Carbonic oxide gas mixed with air to the extent of twenty to twenty-five per cent. destroys the irritability.

“The vapours of chloroform and ether suspend the irritability of the motile organs (for variations of light also), without destroying the life, if the effect does not continue too long.

“Temporary rigor due to electric influence was found by Kabsch to occur in the gynostemium of *Stylidium*. A feeble current acted as a stimulus like vibrations; a stronger one caused a loss of irritability, which returned again, however, after half an hour.”

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CHAPTER XI

THE ELECTRO-PHYSIOLOGY OF THE MOTOR APPARATUS

MUSCULAR TISSUE.

THE two chief varieties of muscular tissue are—

- (1) Unstriated or involuntary muscle, *i.e.*, not under the control of the will.
- (2) Striped or voluntary.

In non-striated muscular tissue the cell substance is longitudinally but is said to be not transversely striated, and each cell seems to have a delicate sheath. Between the fibres there is a small quantity of *cementing* substance. Non-medullated nerves are supplied to plain muscular tissue from the sympathetic or ganglionic system, and this tissue responds but slowly to a stimulus; the contraction spreading as a wave from fibre to fibre.

As it may help us to a clearer understanding of the functioning of the motor apparatus as a whole, we will first consider striated tissue.

STRIATED MUSCULAR TISSUE.

Up to this moment I had not seen, in any work upon Physiology, any illustration of the structure of muscular tissue, but as an electrician I knew what I should find when I betook myself to study. I should find sets of condensers of varying capacity, with an elastic (compressible) substance between each condenser, and with absolute,

elastic, sheath insulation ; the whole being so arranged as to be capable of neuro-electrical contraction in almost every direction. The chain of condensers might, indeed, contract more suddenly, or violently, at one point than at another point or points, but the various contractions would be designed to give, under impulse, a certain definite movement or series of movements to the muscle under excitation.

I now learn from Landois and Stirling's *Text-book of Human Physiology* that each muscular fibre receives a nerve-fibre, or wire from a central station or stations.

The elastic sheath is called sarcolemma, and has transverse partitions stretching across the fibre at regular intervals. Within the sarcolemma is the *contractile* substance of the muscle. This, sarcous, substance is marked transversely by alternate light and dim *layers*, stripes, or *discs*.

These muscular compartments contain the sarcous substance, and in each compartment there is a broad *dim disc*, forming the contractile, or compressible, part, on the upper surface, as shown in the illustration (p. 147) ; then, lower down, a narrower, " clear," homogeneous, soft or fluid substance ; then a membrane (called Krause's membrane), and another clear substance, followed by a dim (compressible) disc, and so on throughout the fibre.

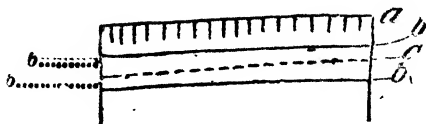
Let us imagine the sarcolemma to be composed of india-rubber, at all events on its inner side, the dim substance to be an elastic buffer, the " clear " lines to be conducting plates or discs, and Krause's membranes or Dobie's lines to be dielectric in character, and condenser action is suggested, once it is conceded that the impulse is neuro-electrical. It is not a question, as I have argued in another chapter, of whether the impulse is neuro-electrical or chemical, but of which action is precedent.

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It will be useful at this stage to bear in mind certain electrical laws—

- (1) The amount of electricity induced by an electrified body on surrounding conductors is equal and opposite to that of the inducing body.
- (2) Induction leads to discharge as well as charge. At contact, or within a distance bridgable by the tension, the charge would be neutralised.
- (8) Faraday called the medium through which induction is propagated, such as air, shellac, paraffin wax, etc., the *dielectric*. Air is taken as 1 and all other substances as more than 1. Air, therefore, is only a bad conductor, not a non-conductor.
- (4) Faraday further supposed the particles or molecules of the dielectric to be conductors insulated from each other; and to this discovery we owe the condenser, and the Farad as the unit of capacity.
- (5) Induction propagates itself in the direction where it has the least resistance to encounter.
- (6) The charge that a body receives is always in proportion to the facilities it offers for induction. If a body is so situated that it has nothing to act on, it receives no charge, or, in other words, has no inductive capacity.
- (7) Discharge begins where the tension is greatest.
- (8) The greater the surface over which electricity is diffused the less its tension at any particular point, and *vice versa*.
- (9) Electricity is exhibited only on the surface of conductors.
- (10) The distribution of electricity on the surface of insulated conductors is influenced materially by their form.
- (11) Electricity concentrates on *points* and *projections*.

The sarcomeres, or divisions of muscular fibre are shown thus—



and such a fibre consists of a number of these divisions, of varying diameter and area. *a* is the dim. contractile part, *b* the clear substance, and *c* Krause's membrane or Dobie's line. We have it on the authority of Noël Paton that the sarcolemma is "a delicate, tough, elastic membrane, closely investing the fibre, and attached to it at Dobie's lines."

Sharpey's drawings of a portion of a human muscular fibre, A, and of separated bundles of fibrils, B, are shown on the next page.

The motor nerves of voluntary muscle are efferent, and therefore the impulse is from the brain, downwards. Suppose, then, we connect these sarcomeres in series in a battery circuit, thus :—

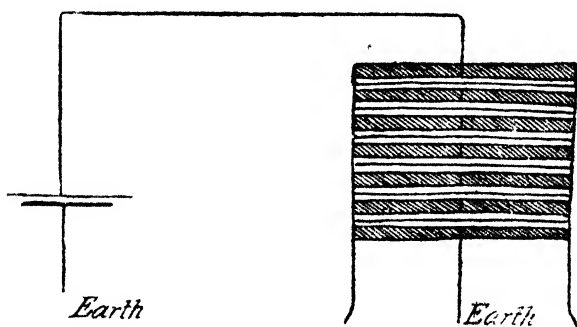


Fig. 71.

The law of electrical attraction would at once come into play. The upper plate would induce electricity, & equal

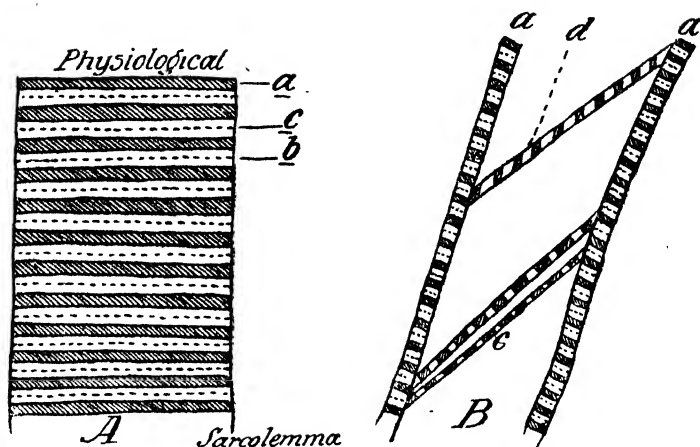


Fig. 72.

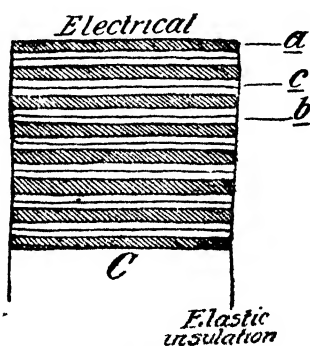


Fig. 73.

Physiological Explanation.—A = portion of a human muscular fibre ; B = separated bundles of fibrils : a, a, larger and d, c, smaller collections. In A the letters a, b, and c represent the *dim* space, the clear spaces, and Krause's membrane respectively.

Electrical Explanation.—In C the letters a, b, and c denote : a, a component filled with an elastic substance, say, viscous india-rubber solution ; b, metallic or other conducting plates ; and c, waxed paper or other dielectric material.

tension but of opposite sign at the lower plate, and that impulse would be transmitted throughout the series, with the result that *contraction* would take place, and the spaces *a* be compressed and bulge at the sides, while the sarcolemma would also be contracted.

The effect would, in fact, be like the compression of a concertina—

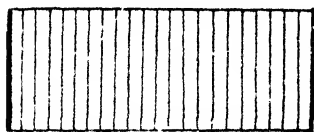


Fig. 74.
CONCERTINA EXPANDED.



Fig. 75.
CONCERTINA COMPRESSED.

except that the projections of the bellows would be rounded instead of diagonal, and assume the appearance of the following figure:—

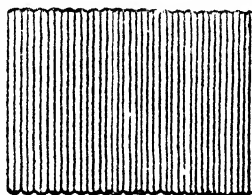


Fig. 76.

But this would only give us a straight “pull,” and as a muscle does not respond to impulse in that way, we must see how Nature overcomes the difficulty, and how discharge or neutralisation is brought about.

From Fig. 72 (B) we see that the fibrils (and it must

include the fibres) are of varying diameter, and we have learned that (1) tension is in the inverse ratio to the surface over which electricity is distributed, (2) electricity concentrates on points or projections, and (3) discharge begins where tension is greatest.

If we were making an artificial muscular fibre we could solve the problem of discharge or neutralisation of charge by placing studs upon our conducting plates, as in Fig. 77,

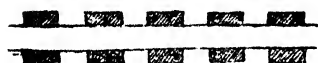


Fig. 77.

because as electricity concentrates on points or projections, and discharge begins where the tension is greatest, the plates would discharge when, by

attraction, they approached each other sufficiently.

We could also vary the "pull" both as regards strength, or velocity, and direction, first by varying the area of some of the sarcomeres, and second by joining them up in groups in series or series-parallel, or parallel.

That Nature does the first is obvious from Fig. 72 (B). As regards the second, we are told that the nerve-fibres of voluntary muscle pierce the sarcolemma and terminate in end-plates, which are shown to connect up with different groups of the sarcomeres of muscular fibre in the following manner :—

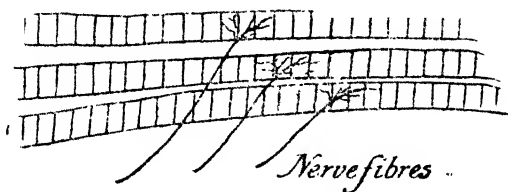


Fig. 78.

Not only is that so, but, if it were desired, the efferent impulse could be converted to an afferent one at any point

by the simple process of inserting a condenser in the nerve circuit :—

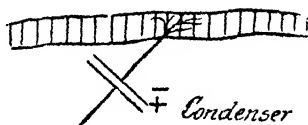


Fig. 79.

or, as it appears to be accomplished in the human body :—

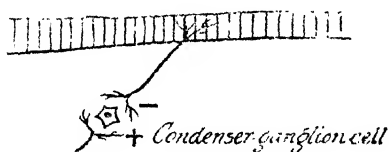


Fig. 80.

both, however, are on exactly the same principle.

We will now compare, briefly, Nature's method of discharge or neutralisation of charge with my suggestion of "studs," and discuss the whole question in detail later on.

As given by Schäfer the sarcomere in a moderately extended condition is shown thus :—

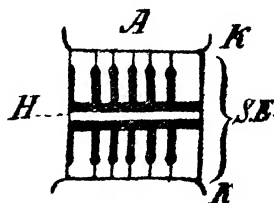


Fig. 81.

k, k are Krause's membranes or Dobie's lines, *H* the plane of Hensen, and *SE* a poriferous sarcous element.

B depicts the sarcomere in contracted condition, compressed and elongated and bulging at the sides.

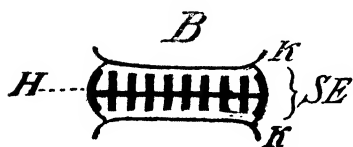


Fig. 82.

The analogy between metallic plates and the "clear" spaces, *b*, of the sarcomere cannot, of course, apply to the material employed, but

only to its electrical character. I am informed that the "clear" spaces are largely composed of potassium salts in fluid or semi-fluid form, and that the dark vertical lines are canals or pores, open towards Krause's membrane, but closed at Hensen's line. The clear spaces are therefore conductive, and the analogy, electrically, holds good. In the contracted muscle the clear part of the muscle substance passes into the canals or pores and *disappears from view*, swelling up and widening the sarcous element and shortening the sarcomere. In the extended muscle, on the other hand, the clear substance passes out from the canals of the sarcous element and lies between it and the membrane of Krause, "again ready for action."

The effect of the completed contraction is to cause the conducting plates to approach each other near enough to enable them to discharge or neutralise their charge by contact through some invisible pore in Hensen's line; or, possibly, by osmosis or diffusion.

Alternatively such action may be made to occur by the plates being withdrawn to a sufficient distance to cause induction to cease. Then, the impulse having passed, they would be restored to their former position, in readiness to resume the performance of their function.

In this connection we may recall the "Muscle telegraph" of Du Bois-Reymond. He attached a piece of muscle to a movable disc and placed the former in the circuit of a

Leyden jar. When connection was made the muscle contracted and the disc was made to move. With two muscles and two discs, battery power, and suitable means for the rapid neutralisation of charge, an electro-mechanical apparatus to exhibit signals in the Morse Code could easily be made.

I have no information as to the composition of Krause's membrane, but if it does not exist and is not a bad conductor of neuro-electricity, then the problem of muscular contraction offers the most extraordinary series of coincidences I ever heard of. In considering this point, however, it must be remembered that a good conductor of high may not conduct low tension electricity at all.

So far, in speaking of the clear spaces, I have used the words "plates" and "discs," but am by no means sure that I am correct in doing so. Schäfer gives an illustration in which the arrangement of the conducting elements

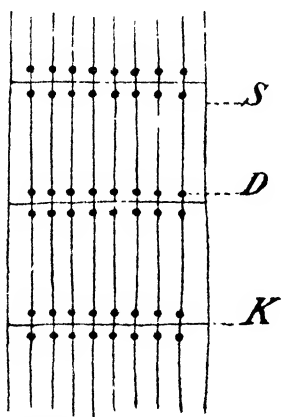


Fig. 83.—PORTION OF LEG-MUSCLE OF INSECT TREATED WITH DILUTE ACID.

S, sarcolemma ; D, dot-like enlargement of sarcoplasm ; K, Krause's membrane. The sarcolemmas are dissolved or at least rendered invisible by the acid. (*Schäfer.*)

appears to my mind to be more consistent with the force exerted by muscle under what must be considered

comparatively feeble stimulus. Electricity concentrates on points and projections, and in that connection the figure assumes a more than usual importance.

We may now study the physiology of muscular fibre to see if there are any accepted facts or views which are antagonistic to ours, and if so, whether they are susceptible of explanation other than that given by the physiologist.

"A nerve-fibre usually enters a muscle at the point where there is the least displacement of the muscular substance during contraction."

The electrician would, of course, connect his line or battery wire in such manner as to avoid interference with the movable or active part of the apparatus.

The next paragraph, from Landois and Stirling, will, I fear, bring me into direct conflict with some accepted views.

"Stimuli are simply various forms of energy, and they throw the muscle into a state of excitement, while at the moment of activity the chemical energy of the muscle is transformed into work and heat, so that the stimuli act as discharging forces . . . the excitability varies as the temperature rises or falls."

I cannot agree with the view that stimuli are *various* forms of energy, holding, as I do, that they—the natural stimuli—are manifestations of neuro-electrical energy; although certain chemical changes are undoubtedly consequent upon them.

Again, it is not altogether correct to say that stimuli act as discharging forces. They act first as *charging* forces, and when contraction has taken place—and not before—cause, as a result of that contraction, discharge or neutralisation of charge.

In regard to the effect of temperature upon the excitability of muscular fibre the explanation can, I venture to think, be given in three words, *i.e.*, "Heat assists conduction."

With a rise of temperature the resistance of the clear substance of the muscle and of Krause's membranes would be reduced; with a fall of temperature the resistance of both would be increased. What the relative fall or rise of resistance is I have no means of determining, but, broadly speaking, a considerable rise of temperature might seriously impair the action of the condenser-compartments (sarcomeres) by breaking down the resistance of Krause's membranes, and so, wholly or partly, short-circuiting the condensers; while a considerable fall of temperature might increase the resistance of the clear substance to such an extent that the low-tension nerve-charge could not overcome it, with the result that the muscle would, temporarily, become paralysed.

A further section deals with excised muscles, and lays stress upon the fact that a series of stimuli of the same strength causes a series of contractions which are greater than at first (Wundt), and argues from that, that although the first feeble stimulus may be unable to discharge a contraction (? cause a contraction) the second may, because the first one has increased the muscular excitability (Fick).

By *excised* muscles I understand *dead* muscles. There is an essential difference between the living and the non-living; but even in non-living muscular fibre we should have condenser-action while its structure remained unimpaired. But it does not follow that the conductivity of the clear substance and the resistance of Krause's membranes would be exactly the same as in living muscle. Discharge cannot occur until contraction is completed, and whereas in living muscle one impulse may be sufficient, a dozen or more might, conceivably, be conveyed to dead muscle before contraction could be completed and discharge or neutralisation effected—if its capacity is altered by death, or some change is brought about by death in the elasticity of the sarcous substance.

Reading on, we are told that "if the muscles of a frog (Du Bois-Reymond) or tortoise (Brücke) be kept in a cool place, they may remain excitable for ten days, while the muscles of warm-blooded animals cease to be excitable after one and a half to two and a half hours. . . . A muscle when stimulated *directly*, always remains excitable for a longer time when its motor nerve is already dead."

I have tested toads and tortoises galvanometrically in years gone by, and have been astonished at their superabundant nerve energy as compared with that of man. Moreover, their insulation, absolute and internal, is such that they can withstand extremes of temperature and exist without food for incredible periods of time. To compare the muscle of a tortoise with that of a warm-blooded animal is to compare an ivy leaf with a deciduous leaf. By reason of its higher insulation the former will live (*i.e.*, remain excitable) for months, whereas a horse-chestnut leaf will perish, under the same conditions, in a few days. It is, to my mind, purely a question of insulation. Supposing there to be any resistance remaining in Krause's membranes and any conductivity in the clear substance, condenser-action would continue—in some degree; but in the dead muscular fibres of warm-blooded animals there would, I should think, be rapid diffusion, short-circuit, and consequent cessation of condenser-action.

The statement that "a muscle when stimulated *directly* always remains excitable for a longer time when its motor nerve is already dead" is almost elementary. Part of the sensory nerve of an apple is its stalk. When the apple is ripe, and it falls, Nature seals the end of the stalk with a resinous insulating substance. Granting, then, the sarcomeres to be structurally intact, a dead motor nerve would be equivalent to the sealed sensory nerve-ending of the apple. On the other hand, if the motor nerve of the muscle was maintained in a moist condition it would *not*

remain excitable for so long a time, nor could the apple continue to resist decay if its stalk was unsealed and wet.

Under the heading "Independent Muscular Activity," I am told that "there are many considerations which show that excitability is independent of the nervous system, although in the higher animals nerves are *the usual medium* through which the excitability is brought into action. Thus plants are excitable, and *they contain no nerves.*" The italics are my own, and emphasise a statement upon which the whole argument depends. That statement also furnishes another illustration of the manner in which the student may be side-tracked from the main line of independent thought and research. He is told by a great authority that plants have no nerves, and, accepting the dictum with the respect invariably accorded to the teacher, is induced to follow a false line of reasoning.

Every plant that grows in the soil has a nervous organisation. The earth is the negative terminal of Nature's electrical system, as the air, in normal conditions of weather, is the positive terminal; and every tree, plant, or vegetable is charged by the earth, through sensory nerves, or closed circuits, extending from the roots through the stem and stalks and thence to the veins (nerve-fibres or fibrillæ) of the leaves. These all yield a negative galvanometric reaction, while those parts of the leaves between the veins, as well as the flower end of all vegetables and fruits, are of positive sign. Not only have plants nerves, but I shall be very much surprised if they are not found to possess a lower form of motor apparatus as well.

I am far from being alone in this opinion. Ainsworth Davis says—

"It has been shown that the protoplasm in adjacent cells may be permanently united by fine threads of the same material passing through the cell-walls. For effecting

movements such an arrangement is invaluable, and this kind of continuity seems to foreshadow the muscular fibres of animals. . . . The 'continuity of protoplasm' has here also an important bearing, and the nerves of animals seem prefigured." It is known that plants suffer from chlorosis, and that it may be cured by putting a little soluble iron in the soil.

Also Sachs says in his *Physiology of Plants* : " It can scarcely be wondered at if the conclusion is drawn that something in the nature of nerves exists in the leaves of *Dionæa*, as appears moreover to accord with the insectivorous propensities of these plants. . . . In any case we have no necessity to refer to the physiology of nerves in order to obtain greater clearness as to the phenomena of irritability of plants ; it will, perhaps, on the contrary, eventually result that we shall obtain from the process of irritability in plants data for the explanation of the physiology of the nerves."

In the vegetable world the various forms of life have their roots in the negative soil, and embryologists have demonstrated that their starch-sugars are of lævo- and their albumins of dextro-rotation. Man has his roots, so to speak, in the positive air, and the rotation of his sugar-glycogen and albumins is directly opposite to that of the plant. That line of thought is worth following, and may be productive of valuable results.

A good deal has been written upon the effect of curara upon motor nerves. My own research has shown that certain poisons increase the resistance of the nerve substance to such an extent that the nerves are unable to transmit impulse ; with the result that there is pain so closely resembling that attendant upon neuritis and sciatica as to introduce error into diagnosis. Moreover, Professor Chunder Bose and I have both found that plants are similarly affected. In a recent experiment I tested a

healthy begonia and obtained a steady deflection of 135 mm. upon the galvanometer scale. The injection of two minims of tincture of *nux vomica* into the stem reduced that deflection to zero in one hour. In six hours the stem fell, the leaves separated at the junction of stalk with stem, and in a week the plant was rotten.

The point laboured by at least some investigators seems to be that although a nerve or nerves may be paralysed or deprived of conductivity by certain poisons, the excitability of muscle may not be so affected, and therefore the muscle is independent of nerve.

Expose that theory to the cold light of reason. In the first place, the poison—the destructive agent—must penetrate not only the nerve but invade the whole of the sarcomeres—as is possibly the case in gas gangrene—if the latter are to be equally affected; secondly, if the resistance of the clear lines of muscular fibre is correspondingly increased, so, conceivably, would be the resistance of Krause's membranes, and therefore contraction might still be possible, though in diminished degree. If it is a matter, merely, of poisoning, or, in other words, "sealing," the motor nerve, the excitability should, according to the theory I have advanced, endure for a longer period than if the nerve had not been poisoned or insulated.

Under the microscope single muscular fibrillæ exhibit the same phenomena as an entire muscle, in that they contract and become thicker. Though there is difficulty in observing the changes that occur in the individual parts of a muscular fibre during the act of contraction, it appears to be certain that the muscular elements become shorter and broader during contraction; that is to say, the transverse striæ approach nearer to each other in the manner I have indicated.

Too much importance should not, for reasons I have given, be attached to experiments with dead muscle unless

the personal equation has been allowed for, but when currents of high tension are employed this may be disregarded and the data viewed from a different standpoint. For example, an illustration of the muscle-curve produced by the application of a single induction-shock to a muscle, as given in Landois and Stirling, is full of interest, although it does not seem to have conveyed its lesson.

Let us see if we can learn anything from it.

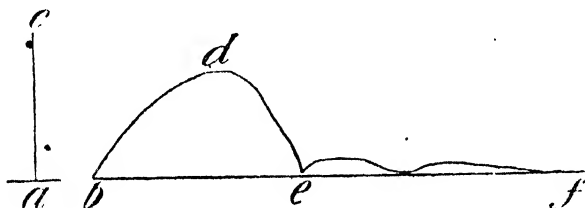


Fig. 84.

af, abscissa; *ac*, ordinate; *ab*, period of latent stimulation; *bd*, period of increasing energy; *de*, period of decreasing energy; *ef*, elastic after-vibrations.

Such is the brief explanation of the curve, but it is, needless to say, elaborated in the text. Any electrician acquainted with submarine cable telegraphy would, however, have in mind what is termed *inductive embarrassment*, and point out the well-known fact that each signal at a receiving station (and muscle is a receiving station) takes a longer time to leave the line than it did to enter it. A momentary signal at starting, it becomes a prolonged signal at its destination, and, furthermore, while a condenser may be partially discharged, as shown by the curve *de*, almost instantaneously, it would continue to discharge along the curve *ef*. All this, I contend, goes to show that the nerve impulse is neuro-electrical, and that muscular contraction occurs through the influence of induction upon condenser-bodies.

At the risk of labouring the fact, I must repeat that the tension at any point is in the inverse ratio to the surface-area over which electricity is distributed. That being so it follows, logically, that the tension at any point or points may be varied by varying the surface-area of the conducting plates, discs, or membranes.

Sarcolemma and Neurilemma.—I have classed these together because, whatever differences may exist between them, they have two properties in common, *i.e.*, they are both elastic and both either dielectric in character, or they carry a dielectric substance or substances upon or in them. If sarcolemma is not, in itself of comparatively high resistance it must carry, on its *inner* side, a resistant substance or material, because, if it were not so carried, contact might occur between the conducting plates or discs or points of the sarcomeres. Also I must assume that the sarcolemma is very elastic, and for this reason. Suppose the sarcolemma not to exist, and that in its place was a layer of dry (highly resistant) air. When an impulse was sent along a motor nerve to cause contraction there would be nothing to impede contraction, and the maximum contractile effect would be obtained. Between this unimpeded movement and movement governed by an elastic material there would be a wide margin of difference—dependent upon the compressibility of the material—and Nature would adjust the degree of elasticity or compressibility to meet requirements.

OTHER INSULATING PROCESSES.

Halliburton gives an illustration of a transverse section of the sciatic nerve of a cat which will repay study.

At first sight one is forcibly reminded of a number of bundles of insulated wires laid in bitumen in a trough, and we shall, I think, be led to the conclusion that that view

is not without foundation when we examine the figure in detail.

Let us first unravel a piece of ordinary electric-light "flex." In the centre are a number of fine copper wires

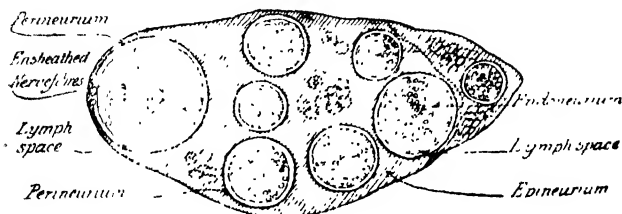


Fig. 85.

which we will call fibrillæ. The first insulating layer is composed of red cotton, and this we will imagine to be the endoneurium. The next outer layer is of white cotton (lymph space), while the outer layer or perineurium is of green silk—a very highly-resistant material.

In the illustration given above it will be seen that each bundle of nerve-fibres is encircled by a lymph space lying between two insulating processes (endoneurium and perineurium), and as lymph is alkaline and therefore conductive, another problem is presented for solution.

What, in this particular instance, is the function of lymph?

Suppose the nerve-fibres to be insulated wires connected in a special circuit for a special purpose, and further imagine these wires to run more or less parallel with hundreds or thousands of other wires in different branch circuits, each or all of which would be conveying currents or transmitting impulses in the same or opposite directions. The result would be inductive interference with the fibres of the sciatic nerve, and the impulses transmitted by them would be liable to continued interruption.

A practical remedy, if we were dealing with bundles of insulated wires, would be to copper-tape each bundle or put it in a metal tube, so that induced currents could be intercepted by the tape and tube and prevented from reaching the actual conductors, the wires or nerve-fibres. That appears to be the most reasonable view to take of the function of lymph in this case. It is hardly possible to regard it as an insulating substance, despite its tendency to clot and form a "colourless coagulum of fibrin," in view of the more probable explanation I have suggested.

Again referring to the figure and adhering to our simile of bundles of insulated wires, it will be evident that if we arrange these in a trough and pour melted bitumen around them the bitumen would form an enveloping sheath, corresponding, roughly, to the epineurium.

We will take, as another example, the core of a submarine cable. The conductors—of which there are usually eight or more—are separated from each other by gutta-percha, and the total insulation is made up of three layers of gutta-percha and three layers of Chatterton's compound, superimposed one upon the other.

As an instance of what is done in practice I will quote from Herbert's *Telegraphy*.

In the telegraph system of the post-office there are, of course, a large number of telegraph and telephone circuits, which by reason of their being in juxtaposition require about the same measure of protection from induction as the multifarious fibrillæ of the sciatic nerve.

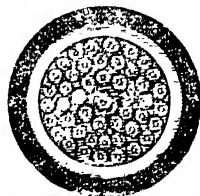


Fig. 86.—SECTION OF A SCREENED CABLE.

In order to get rid of inductive interference various devices, such as twisting the wires, were tried with more or less success, but the method which has given the best results is thus described by Mr. Herbert: "The conductor

is first covered with three wrappings of paper, the first of which may be either spiral or longitudinal, but the other two are invariably applied spirally. The spiral wrappings are applied so as to form a helical air-space throughout the length of the core. The conductor thus insulated is then enclosed in a final wrapping of paper, forming a closed helix without overlap. Over this is laid a helical winding of *copper tape*, with an overlap. . . . The whole of the cores are laid together, and a seamless cylindrical sheathing of lead, at a temperature of 600° F., is applied to the cable."

This description refers, needless to say, to a land cable, and the paper and air insulation are designed to reduce the capacity.

"The copper tape forms a continuous conducting tube around the wire, and as this tube is earth-connected, either by direct contact with the lead sheathing or indirectly by the tapes of the other cores, it will be obvious that induction between the wires cannot occur. Firstly, Faraday's experiments showed that variations in the differences of potential existing or produced between conductors within a metallic covering produce no effect outside that covering. Secondly, any source of inductive disturbances brought to bear upon a screened conductor produces the whole of its effects upon the copper tape. The magnetic lines of force induce currents along the tape covering the wire, and as this path is highly conductive, practically the whole of the energy is absorbed by it. In order to produce an inductive effect, currents must be generated in the tape of the disturbing wire and also in the tape of the disturbed wire before the second conductor is reached."

It is at least a coincidence that in the "flex," the cable and the nerve, the axis cylinder should be composed of a bundle of funiculi instead of one wire, and that the insulation should take the form of several layers of a semi-plastic

material. One might, indeed, be tempted to think that while the physiologist has held the electrician more or less in contempt, the latter has achieved his object by copying certain of the natural processes described by the former. That this is so is, however, open to doubt, because it is questionable whether at the inception of telegraphy there was in existence any illustration published of the nervous system of man which could have so guided or inspired the electrician. Moreover, it is difficult to believe that were these systems of insulation borrowed from or suggested by any physiological work we should have remained in ignorance of the true functioning of the nervous system for so long a period of time. The explanation, no doubt, is that the electrician discovered certain natural laws and, applying them, unconsciously imitated the work of the Creator.

TERMINATION OF NERVES IN MUSCLE.

In the *voluntary muscles* the motor nerve-fibres have special end-organs called end-plates. In the *involuntary muscles* the fibres form complicated plexuses near their termination. . . . Considerable variation in the shape of the end-plates occurs in different parts of the animal kingdom. In the voluntary muscles the fibre branches two or three times, and each branch goes to a muscular

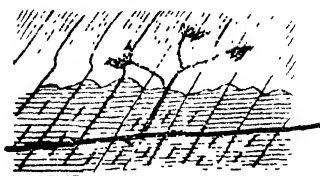


Fig. 87.

(After Schäfer.)

fibre. Here the neurilemma becomes continuous with the sarcolemma, the medullary sheath stops short, and the axis cylinder branches several times.

A termination of medullated nerve-fibres in tendon near the muscular insertion is shown by Golgi (Fig. 87), but more interesting is Szymonowicz's drawing of end-plates with the axis cylinders and their final ramifications of fibrillæ, as it also makes it clear that the muscular fibres vary in diameter and therefore in tension also.

The word "plates" is confusing. They do not look like plates, but more closely resemble bunches of wire. The term "end-organs" is in keeping with their appearance and probable function, and we will so refer to them.

We must not for one moment depart from our hypothesis of the condenser-compartment action of muscular fibre, nor forget that the contraction of muscle is not along a straight line but in curves, and, furthermore, that the sarcomeres of a muscular fibre may not be required to be, and obviously are not, connected wholly in series.

Suppose these end-organs to be composed of fibrillæ, stretching to and connecting with different sets of sarcomeres, in such manner that those, and those alone, would be *directly* stimulated or acted upon, and we may begin to comprehend in some measure their function and distribution.

Professor Rosenthal gives the following account of the termination of nerve in muscle: "*The nerve passes into direct contact with the muscle-substance. . . . The nerve-fibres, in their course within the muscle, touch externally many muscle-fibres, over which they pass before they finally end at another muscle-fibre . . . only those pulsate at which the nerve-fibre ends. . . . The nerve-sheath is, as we already know, a real isolator as regards the process of excitement within the fibre; for an excitement within a nerve-fibre remains isolated in this, and is not transferred to any neighbouring fibre. It is quite impossible, therefore, that it can transfer itself to the muscle-substance, since it is separated from the latter*

not only by the nerve-sheath, but also by the sarcolemma.

But if the nerve-fibre penetrates the sarcolemma, and if nerve-substance and muscle-substance are in immediate contact, then the transference of the excitement present in the nerve to the muscle-substance is intelligible."

The plexuses of the involuntary muscles probably form part of a closed-circuit system designed to maintain equilibrium. The plexus of Auerbach, as shown in Halliburton, is, roughly, thus:—

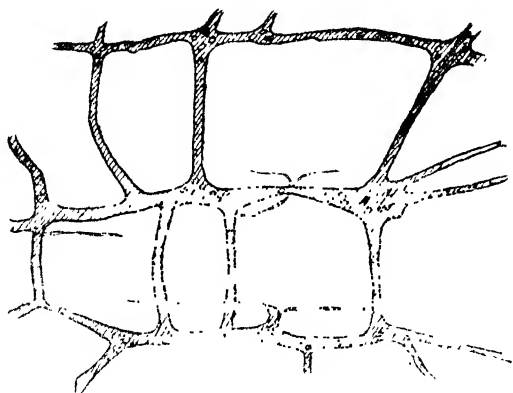


Fig. 88.—PLEXUS OF AUERBACH.

(After Cadiat.)

Without unduly taxing the imagination one could conceive that plexus to be a distributing and equalising station, provided in each of its branches and throughout its ramifications with condensers of adjusted capacity, so that at each and every point there would be, in normal health, a certain given and definite tension. By "equalising" I mean an automatic "give-and-take" arrangement to neutralise any excess or compensate for any deficiency.

DENDRONS AND SYNAPSES AND THEIR PROBABLE FUNCTION

The grey matter of the cerebellum contains a large number of small nerve-cells, and one layer of large cells. These are flask-shaped and are called the *cells of Purkinje*. The neck of the flask breaks up into branches, and the axis cylinder process comes off from the base of the flask.

The whole nervous system consists of nerve-cells and their branches, supported by neuroglia (epiblastic or insulating material) in the central nervous system, and by connective tissue (binding and more or less non-conductive) in the nerves. Some of the processes of a nerve-cell break up almost immediately into smaller branches, ending in arborescences of fine twigs; these branches are now called *dendrons*. One branch becomes the long axis cylinder of a nerve-fibre, but it also ultimately terminates in an arborisation; it is called the *axis cylinder process*, or, more briefly, the *axon*. The term *neuron* is applied to the complete *nerve-unit*, that is, the body of the cell, and all its branches. The cell processes are said to contain Nissl's granules, but we have it on the authority of Dr. Mott that these do not exist, as such, in the living cell, and probably not therefore in the living dendron (see p. 190).

Such is a brief physiological description of the dendrons and the processes associated with them, and from it there does not at first sight appear to be any intimate connection between them and the synapses. If, however, they are considered in the light of Cajal's illustration of the synaptic connections of sympathetic cells from the superior cervical ganglion of man, as given by Schäfer (see Fig. 90), it will be seen that the evidence points to the dendrons being branch-circuits, the arborisations having the function of condensers, or Leyden jars; each synaptic junction or

dielectric process offering resistance, and 'herefore interposing delay to the passage of the current or impulse.

Halliburton has told us, and it is an important fact to remember, that each nerve-unit is anatomically independent of every other nerve-unit. The arborisations interlace and intermingle, and nerve impulses are transmitted from one nerve-unit to another, through *contiguous*, but not through *continuous* structures. Furthermore it is open to question whether a so-called continuous current of electricity is continuous in the strictest sense of the word, or whether it is really a series of polarisations and discharges occurring with such velocity as to appear to be continuous.

Put shortly, the views taken of the propagation of electric force by molecular action consider the molecules of the interpolar wire to be as follows :—



Fig. 89.

c being the copper and *z* the zinc end, the shaded parts being + and the unshaded —. The first effect of the electric force developed by the chemical affinity of the zinc for the O or SO₄ is to throw all the molecules of the circuit into a polar condition, the force being transmitted from molecule to molecule in both directions. Positive and negative electricities appear in each molecule of the circuit; and if the action be powerful enough, discharge takes place throughout the whole, each molecule giving out its electricities to those next it, which, throwing out the opposite electricities, produce electric quiescence throughout. A constant series of such polarisations and discharges, taking place with enormous rapidity, constitute a current.

In the body the impulse may be, and probably is,

induced in and not transmitted through a contiguous structure, in the same manner that a current passing along one insulated wire may induce a current in another, contiguous but not continuous, insulated wire ; of opposite sign understood.

The following is a sketch from the drawing I have mentioned :—

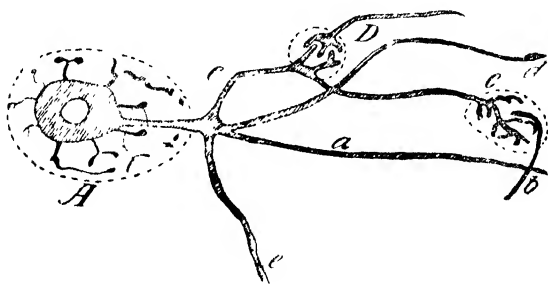


Fig. 99.

(After Cajal.)

Synaptic connections of a sympathetic cell from the superior cervical ganglion of man.

A = cell with well-marked intracapsular dendrons ; C, D = synapses between dendrons outside the cell capsules ; a = axon ; b, d, c, e = extracapsular dendrons.

Let us assume that the cell A is the source or container of energy and that D is a typical synapse , I say D because its structure is more clearly marked than that of C.

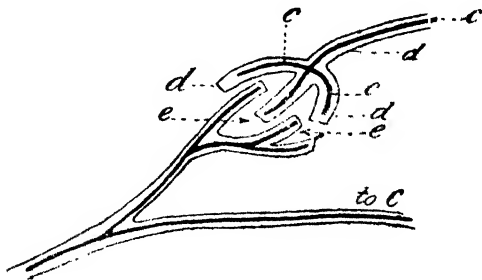


Fig. 91.

Let the dark lines, c, c, c, represent conductors ; d, d, d, non-conductors, and e, e, e, connective tissue.

Furthermore, we will draw D upon a larger scale, as I imagine it to be (see Fig. 31).

We can have no doubt that *c, c, c* are conductors because they transmit impulses; *d, d, d* must be dielectrical in character, as they are designed to conserve energy in the axon, and there is reason for the belief that both neuroglia and connective tissue are non-conducting substances.

A condenser, as used in telegraphy, is conventionally shown in illustration, and the analogy, if we pursue it, is rather remarkable. In the figure only the conducting plates are shown. Let us insert the dielectric, and the synaptic connection appears to be a condenser of large surface-area, but possibly, by reason of the points or projections, of comparatively high tension.

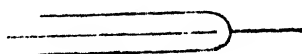


Fig. 91A.

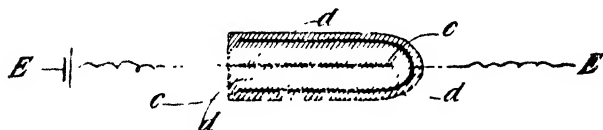


Fig. 92.

According to Schäfer, the "arborisations from different cells may interlace with one another (as in the olfactory glomeruli, in the retina, and in the sympathetic ganglia), or a terminal arborisation from one cell may embrace the body or the cell-processes of another cell; as with the cells of the spinal cord and the cells of the trapezoid nucleus of the pons Varolii, and in many other places. The term *neuro-synapse* may be applied to these modes of junction. By them nerve-cells are linked together into long chains of neurons, the physiological path being *uninterrupted*, although the anatomical path is believed to be interrupted at the synapses."

From this it would appear that the two arborisations as shown in the enlarged sketch of D (Fig. 91) may actually touch or embrace each other, so that no additional resistance may be offered by *intervening* connective tissue, but even in such case there would be two thicknesses of dielectric (d, d) to one of conductor (c) in the path of the impulse, and the result must be delay during the accumulation of tension at the arborisation nearest the cell, the plates being further apart.

As the cell is in the superior cervical region two things follow, logically : *i.e.* (1) the impulse from it is efferent, and (2) the tension in the dendron is comparatively high. We know also that electricity concentrates upon points or projections, and the arborisations appear to be constructed in accordance with this law.

When we are able to examine the structure of the brain, I think the evidence in support of the human organism being neuro-electrically controlled—with consequent chemical action—will be even more convincing than that I have already adduced.

One thing stands out prominently—and it cannot be given too great prominence—*this vital action, neuro-electrical or chemical, or both, cannot go on unimpaired if the natural insulation resistance, in any part of the body, is broken down or interfered with.*

CONNECTION OF MUSCLES AND BONES, ETC.

If, in addition to a consideration of the different behaviour of muscular tissue owing to differences of tension, quantity, and resistance, we unite a brief survey of their connection with bones, we may obtain a still better grasp of the subject. As a considerable number of muscle-fibres constitute the trunk of the muscle, strong slender threads of the nature of connective tissue unite into cords which

are called the muscle-tendons. They are sometimes short, sometimes long, thicker or thinner according to the size of the muscle, and they serve to attach the muscles firmly to the bones, to which, acting like ropes, they transmit the tension of the muscles. One of the two bones to which a muscle is attached is usually less mobile than the other, so that when the muscle shortens, the latter is drawn down against the former. In such a case the point of attachment of the muscle to the less mobile bone is called its origin, while the point to which it is fixed on the more mobile bone is called its attachment (*epiphysis*). For instance, there is a muscle which, originating from the shoulder-blade and collar-bone, is attached to the upper arm-bone; when this muscle is shortened the arm is raised from its perpendicular pendant position into a horizontal position. A muscle is not always extended between two contiguous bones. Occasionally passing over one bone, it attaches itself to the next. This is the case with several muscles which, originating from the pelvic bone, pass across the upper thigh-bone and attach themselves to the lower thigh-bone. In such cases the muscle is capable of two different movements: it can either stretch the knee, previously bent, so that the upper and the lower thigh-bones are in a straight line, or it can raise the whole extended leg yet higher and bring it nearer to the pelvis. But the points of origin and of attachment of muscles may exchange offices. When both legs stand firmly on the ground the above-mentioned muscles are unable to raise the thigh; instead, on shortening, they draw down the pelvis, which now presents the more mobile point, and thus bend forward the whole upper part of the body. . . . In a previous examination of the action of muscle we have dealt with an imaginary muscle, the fibres of which were of equal length and parallel to each other. Such muscles do really exist, but they are rare. When such a muscle shortens, each of its fibres

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acts exactly as do all the others, and the whole action of the muscle is simply the sum of the separate actions of all the fibres. As a rule, however, the structure of muscles is not so simple. According to the form and the arrangement of the fibres, anatomists distinguish short, long, and flat muscles. The last mentioned generally exhibit deviations from the ordinary parallel arrangement of the fibres. Either the fibres proceed at one end from a broad tendon, and are directed towards one point from which a short round tendon then effects their attachment to the bones (fan-shaped muscles), or the fibres are attached at an angle to a long tendon, from which they all branch off in one direction (semi-pennate muscles), or in two directions like the plumes of a feather, (pennate muscles). In the radiate or fan-shaped muscles *the pull of the separate parts takes effect in different directions*. Each of these parts may act separately, or all may work together ; and in the latter case they combine their forces, as is invariably the case with forces acting in different directions, in accordance with the so-called parallelogram of forces. As an example of this sort of muscle the elevator of the upper arm (the deltoid muscle) may be examined. Contractions of the separate parts really occur in this. When only the front section of the muscle contracts, the arm is raised and advanced in the shoulder-socket ; when only the posterior part of the muscle contracts, the arm is raised backward. When, however, all the fibres of the muscle act in unison, the action of all the separable forces of tension constitutes a diagonal which results in the lifting of the arm in the plane of its usual position.

“ In some semi-pennate and pennate muscles the line of union of the two points of attachment does not coincide with the direction of the fibres. When the muscle contracts each fibre exerts a force of tension in the direction of its contraction. All these numerous forces, however, produce

a single force which acts in the direction in which the movement is really accomplished, and the whole action of the muscle is the sum of these separate components, each derived from a single fibre. In order to calculate the force which one of these muscles can exert, as well as the height of elevation proper to it, it would be necessary to determine the number of the fibres, the angle which each of these makes, with the direction finally taken by the compound action, as well as the length of the fibres—these not being always equal. . . . The direction in which the action takes effect does not, however, depend only on the structure of the muscle, but chiefly on the nature of its attachment to the bone. Owing to the form of the bones and their sockets, the points of connection by which the bones are held together, the bones are capable of moving only within certain limits, and usually only in certain directions. For instance, let us watch a true hinge-socket, such as that of the elbow, which is capable only of bending and stretching. As, in this case, the nature of the socket is such that motion is only possible in one plane, the muscles which do not lie in this plane can only bring into action a portion of their power of tension, and this may be found if the tension exercised by the muscle is analysed in accordance with the law of the parallelogram of forces, so as to find such of the component forces as lie within the plane.” (Rosenthal, 1895.)

Here it may be useful to give a brief description of what is meant by the parallelogram of forces, my authority being Dr. M'Gregor-Robertson.

Let O, in the figure on next page, be a particle under the influence of two forces, one, OB, urging it in the direction of B, and the other, OA, urging it in the direction of A. It is evident that the particle cannot proceed along either path, but will choose a path which is a compromise between the two. It will move upwards. Let a third force, represented by the weight, be applied to O, and let this

third force be adjusted so that O remains in its original position, and suppose the weight to represent a force of 1 lb. Then O is under the influence of three forces; but it

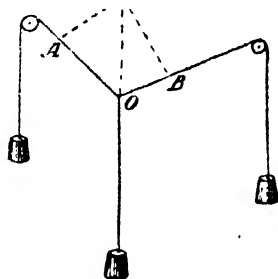


Fig. 93.

is at rest, so that the forces are in equilibrium. The forces OA and OB are both tending to draw O upwards, and they are completely counterbalanced by the 1 lb. weight. To put it another way, the weight is tending to pull O downwards, but is counterbalanced by OA and OB. But the weight would be counterbalanced exactly by a force of 1 lb. acting in the direction directly opposed to it, that is, in the direction of the straight line drawn up from O. If, therefore, OA and OB be withdrawn, and one force substituted equal to the weight opposing them, equilibrium will still be maintained. So the two forces OA and OB can be replaced by a single force, which is called the *resultant force*. If a parallelogram be constructed on OB, OA, as indicated in the following figure, it will be seen that the

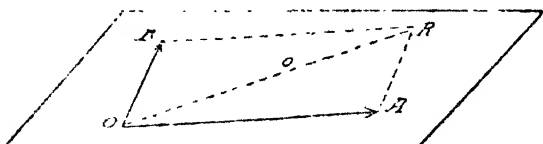


Fig. 94.

resultant force is the diagonal of the parallelogram. The two forces OA, OB, are acting on a particle. To find the

direction in which the particle will move, a parallelogram is constructed of which OA and OB form two sides, and then the diagonal OR of the parallelogram is drawn. It gives the direction which the particle takes ; it is the resultant of the two forces OA, OB ; and if the lines OA and OB represent by their lengths the magnitude of the forces, then the diagonal will represent by its length the magnitude of the resultant force. This is the parallelogram of force.

In a similar way one force may be made to take the place of several forces. Let a parallelogram be constructed on the lines representing two of the forces. Take the diagonal, and with it and the line representing the third force construct another parallelogram. Its diagonal is the resultant of the three forces ; with it and the line representing the fourth force, the resultant of four forces may be found, and so on.

“ It is different in the case of the more free ball-sockets, which permit movement of the bone in any direction within certain limits. When a socket of this sort is surrounded by many muscles, each of the latter, if it acts alone, sets the bone in motion in the direction of its own action. If two or more of the muscles assume a state of activity at the same time, then the action will be the resultant of the separate tensions of each.

“ There is yet another way in which the work performed by the muscles is conditioned by their attachment to the bones. The latter must be regarded as levers which turn on axes, afforded by the sockets. They usually represent one-armed, but sometimes two-armed levers. Now, the direction of the tension of the muscles is seldom at right angles to that of the movable bone lever, but is usually at an acute angle. In this case, again, the whole tension of the muscle does not take effect, but only a component, which is at right angles to the arm of the lever. Now, it is noticeable that in many cases the bones have projections

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or protrusions at the point of attachment of the muscles, over which the tendon passes, as over a reel, thus grasping the bone at a favourable angle; or, in other cases, it is found that cartilaginous or bony thickenings exist in the tendon itself (so-called sesamoid bones), which act in the same way. The largest of these sesamoid bones is that in the knee, which, inserted in the powerful tendon of the front muscle of the upper thigh, gives a more favourable direction to the attachment of this tendon than there would otherwise be." (Rosenthal.)

I have quoted at considerable length from Professor Rosenthal, but his explanation of the connection of muscles with bones is so lucidly given, that while I may be in need of his forgiveness I owe no apology to my readers for the digression. The measure of my offence is, however, not ended. So far we have been dealing with voluntary muscle. It now remains to examine plain muscle in respect of which physiological works in general are comparatively silent. We are told that they are longitudinally but *not transversely* striated, and I cannot reconcile this with "shortening and broadening" due to the electrical law of attraction and repulsion. This, however, we will consider in its proper place.

RESPONSE OF HUMAN MUSCLES AND NERVES TO ELECTRICAL STIMULATION

As this has an important bearing upon the theoretical explanation I have so far given of the electro-physiology of the motor apparatus, it may be permissible to quote and comment upon Halliburton. He says: "When the nutrition of the nerves is impaired much stronger currents of both the induced and constant kinds are necessary to evoke muscular contractions than in the normal state."

If for "nutrition" we read "conductivity" comment is unnecessary.

“When the nerves are completely *degenerated* (as, for instance, when they are cut off from the spinal cord, or when the cells in the cord from which they originate are themselves degenerated, as in infantile paralysis), no muscular contraction can be obtained on stimulating the nerves, even with the strongest currents.”

Obviously, there is a complete loss of conductivity. In the old days the cables laid in South American waters were insulated with india-rubber. The sulphur in the rubber caused rapid degeneration of the conductors, and the application of 1,000,000 volts at A would not cause a receiving instrument at B to contract, by reason of a break or breaks of continuity.

“The changes in the excitability of the muscles are less simple, because in them there are two excitable structures, the terminations of the nerves (end-organs) and the muscular fibres themselves.”

It is open to question whether the end-organs are not inducing bodies. Nowhere do they appear to make actual contact; that is to say, they do not connect as wires are connected so that a direct current flows through them, but appear to act inductively upon the organs they influence.

“Its excitability” (that of muscle) “corresponds in degree to that of the nerve supplying it.”

In accordance with Ohm’s law the degree of excitability of the muscle would be governed by the resistance of the motor nerve supplying it.

“The fact that, under normal circumstances, the contraction which is caused by the constant current is as quick as that produced by an induction shock, is ground for believing that in health the constant, like the induced current, causes the muscle to contract chiefly by exciting the motor nerves within it.”

Tensions being equal, the effect of an induction shock is not, cannot be, the same as the effect produced upon

muscle by an impulse originating in a constant or direct current of normal potential. In both cases the motor nerves convey the impulse or impulses to muscular fibres, but the muscular response cannot, in my judgment, be identical.

“When the motor nerve is degenerated, and will not respond to any form of electrical stimulation, the muscle loses all its power of response to induction shocks. The nerve-degeneration is accompanied by their rapid wasting, and any power of response to faradism they possessed in the normal state is lost.”

That naturally follows.

“But the response of the muscle to the constant current remains, and is, indeed, more ready than in health.”

The meaning here is somewhat obscure. If it is sought to convey the constant current to the muscle by means of the degenerated motor nerve, and there is a complete break of continuity, no current could pass and no response be given. If, however, the sarcomeres are stimulated *directly* the normal resistance of the motor nerve would be eliminated and the muscle should certainly give a readier response. This may be what is meant, because we have been told that “when the motor nerve is degenerated and will not respond to *any* form of electrical stimulus the muscle loses all its power of response to induction shocks.” But the phenomenon may be due to the end-organs, as well as the motor nerve-fibres, transforming or modifying in normal health an induction shock—a momentary impulse—so that the muscle could respond to it, and that after degeneration no such modification could occur.

“Suppose a patient comes before one with muscular paralysis. This may be due to disease of the nerves, of the cells of the spinal cord, or of the brain. If the paralysis is due to brain disease, the muscles will be slightly wasted owing to disuse, but the electrical irritability of the

muscles and nerves will be normal, as they are still in connection with the nerve cells of the spinal cord which control their nutrition."

True. But where does the impulse originate, normally? In a nerve cell or cells in the motor area of the brain. If that cell or those cells fail to act, no impulse can pass from brain to muscle. In other words, the rest of the apparatus is in working order, but some of the battery cells have given out.

"But if the paralysis is due to disease either of the spinal cord or of the nerves, this nutritive influence can no longer be exercised over the nerves or muscles."

Of course not. There is a partial or total loss of conductivity by reason of the influence of disease upon the spinal cord or the nerves. The motor apparatus generally may be in working condition, but no energy can be conveyed to it, and it cannot, therefore, be set in motion.

CHAPTER XII

CARDIAC MUSCLE

THE problem of the structure and precise functioning of cardiac muscle is not easy of solution, owing, in the main, to the absence of diagrams illustrating its connections. Several facts, however, stand out prominently.

It is said (1) to be intermediate in structure and properties between voluntary and involuntary muscle ; (2) to contract more slowly than ordinary striped muscle ; (3) to be striated ; and (4) to have no true sarcolemma, " although there is a thin superficial layer of non-fibrillated substance." (Schäfer.)

Considering, as we must do, each segment as a sarcomere, it will be seen that the segments differ in length and in diameter (permitting of infinite variation of tension) ; that some are non-nucleated, and that there are branch, or shunt, circuits which no doubt play their part in the inductive regulation of tension in an automatic neuro-electrical system, because, although the heart's action may be subject to psychological influences, it must be supplied, from within or without, with energy unintermittently, and therefore must form part of an *automatic* system.

And here, perhaps, we may begin to appreciate the beautiful regulation exercised by the vagus nerves. The energy, partly self-contained or not, which, in life, is

constantly supplied to the heart, is by way of the sympathetic, while the vagus nerves are inhibitory, or, in other words, exert a governing or opposing electromotive force. They are buffers, or springs, regulating the flow of energy to the heart, much in the same way that a rise or fall of temperature may regulate the fall or rise of a gas-flame in a heating apparatus.

We learn, from physiological research, that man inhales 400 c.c. of oxygen per minute during the daytime and 200 c.c. per minute during the night. I know, from my own work, that if the hand-to-hand galvanometric deflection of a normally healthy man during the daytime is 350 mm. it will fall at night to about 175 mm.

That means there is a falling off in the production or reception of nervous energy of fifty per cent.

But the controlling, governing current from the brain—the inhibiting current—is also halved, because generation, or reception, is halved, and therefore there is no alteration in equilibrium, and the heart must receive a proportionate supply of energy at all times, supposing there to be no escape of nerve-current or excitement of the vagi. Should such an escape occur, the result, or one result, should be higher blood-pressure, while in the event of anything, such as cold or some toxin, increasing the resistance of the conducting substance of the vagi, the same phenomenon should be presented, because inhibition would be diminished. On the other hand, any cerebral disturbance tending to unduly stimulate the cardiac branches of the vagi would have the effect of slowing the heart down, possibly in extreme cases to a fatal extent.

The main differences, so far as I can see, between voluntary and cardiac muscles are: (1) the first are supplied by open circuits through which impulses are sent from the brain; (2) cardiac muscles form part of a closed circuit or circuits regulated by cell-groups possibly other than

unipolar; (3) voluntary muscles contract in parcels of sarcomeres and not necessarily in one direction; and (4) cardiac muscles contract in "walls," rhythmically, and as the rate of propagation of the wave is slower than in voluntary muscles, their inductive capacity, and possibly their resistance, must be greater, probably by reason of the conducting surfaces being connected, mainly if not entirely, in parallel (see also p. 94).

PLAIN MUSCLE

In regard to plain muscle there is, as I have remarked elsewhere, a lack of information. To my mind there can be no manner of doubt that they are transversely striated, although the striæ are too small to be clearly observed.



Fig. 95.—MUSCULAR FIBRE-CELL FROM THE MUSCULAR COAT OF THE SMALL INTESTINE.
(After Schäfer.)

I am forced to this conclusion by several considerations, one of which is that it is difficult to conceive how they can shorten and broaden if only longitudinally striated. They would flatten but not shorten. Professor Rosenthal says: "It must be observed that the distinction between striated and smooth muscle-fibres is not absolute; for there are transitional forms, such as the muscles of molluscs. The latter consist of fibres, exhibiting to some extent a striated character, and, in addition to this, the character of double refraction. At these points the disdiaclasts are probably arranged regularly and in large groups, while at other points (as in true smooth muscle-

fibres) they are irregularly scattered and are therefore not noticeable."

Nor does Schäfer really commit himself definitely to the statement that plain muscle is not transversely striated. He says: "Plain muscular tissue is composed of long, somewhat flattened, fusiform cells *which vary much in length*.

"Each cell has an oval or rod-shaped nucleus, which shows the usual intra-nuclear network, and commonly one or two nucleoli. The cell-substance is finely fibrillated, but does not *exhibit cross-striae like those of voluntary muscle*. There appears, as in cardiac muscle, to be a delicate non-striated external layer, probably a stratum of undifferentiated protoplasm, certainly not a true sarcolemma. . . . There is a little intercellular substance which is bridged across by filaments passing from cell to cell. Some authorities, however, deny that the involuntary cells are thus connected, and hold that the appearance of bridging fibres is due to intercellular connective tissue. *It is, however, difficult to understand how the contractions are propagated from cell to cell if there is no sort of continuity between the cells.*" *

Now, in regard to the speculative explanation I am about to give, it is very necessary to remember that this tissue responds but slowly to a stimulus, and that the contraction spreads as a wave from fibre to fibre. If we depart from the theory of condenser-action the problem must, so far as I am concerned, remain without attempt at solution, but if we adhere to it we may begin to see daylight.

These fibres of involuntary muscle are, admittedly, longitudinally striated. They, however, contract and become shorter and broader. It is quite evident that with condenser-action and longitudinal striation only they would merely flatten (Figs. 96; 97) :—

* The italics are mine.



Fig. 96.

Before contraction.



Fig. 97.

During contraction.

whereas, I take it, what really happens is this, roughly :—



Fig. 98.

Before contraction.



Fig. 99.

During contraction.

For this to occur it is not at all necessary for the fibres to be transversely striated as voluntary muscle is striated. All that is required is that they should possess something of the nature of an elastic sarcolemma—and the external

layer must be elastic to permit contraction—and that they should be bridged at intervals by some non-conducting substance, possibly connective tissue. Condenser-action would then take place as in voluntary tissue, and the rate of propagation of the impulse would be governed by the considerations set forth in the chapter upon Inductive Capacity.

In this manner we can perceive how the contraction spreads as a wave from fibre to fibre, and why it is that the cells vary much in length. They also, no doubt, vary much in diameter in order to enable the tension to be varied, but there is this essential difference, I think, between voluntary and plain muscle: the former is required to contract in curves, at different velocities in the course of those curves and not in the same direction throughout, while the function of the latter is merely to shorten.

If that is so a less complicated form of fibre would serve the purpose, nor would the complex end-organ connections be necessary. We cannot compare the cells, for reasons I have given, to a chain of condensers in series, *i.e.* $\text{---}||\text{---}||\text{---}||\text{---}||\text{---}$, but must imagine them to be connected in parallel or series-parallel. Nor is this opinion without warrant, as the following figure goes to show :—

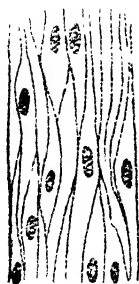


Fig. 100.—MUSCLE-CELLS OF INTESTINE (SZYMONOWICZ), MAGNIFIED 530 DIAMETERS. (After Schäfer.)

“The fully-formed muscle retains its syncytial character, and is not formed by completely separated cells.” (Schäfer.)

In conclusion, my considered opinion is that while plain muscle is not transversely striated in the sense that voluntary muscle is transversely striated, the longitudinal fibres are bridged across by some non-conducting substance, and that the chief difference in the structure of the two is the absence in the former of the sarcous element. As, however, the charge, instead of being neutralised at various points, passes as a wave from cell to cell, the sarcous element can naturally be dispensed with.

CHAPTER XIII

NISSL'S GRANULES

THAT many of the nerve cells, if not all of them, contain organically combined iron, as suggested by Macellum, I do not doubt, but the weak link which has hitherto existed in my chain of reasoning has been the manner in which Nissl's granules—so-called—have been shown, in physiological and histological works, to be distributed in the cell contents.

As will be seen from Figs. 109, 110 (taken from Schäfer), they appear as masses, and this is not quite consistent with the theory that neuro-electricity is generated by the association of iron with oxygen in the protoplasm. One would expect to find iron in the form of minute particles arranged in the cell contents in a well-defined manner; a manner which, if it could be seen with a sufficiently high power, would make it clear how electrical attraction and repulsion as well as generation are brought about. In health not only does the nucleus occupy a central position in the cell, but the nucleolus is more or less centrally situated in the nucleus, and this phenomenon, as well as that of amœboid movement, would seem to have its origin in electrical activities and to be in accordance with the experiments of Ampère.

With iron in the shape of irregular masses it is difficult to see how this harmonious result is arrived at, no matter how convinced we may be that it is so.

The illustrations to which I have referred were based

upon experiments with dead cells, and I have always contended that the difference between the living and the non-living is so great as to render results with the latter not only almost nugatory but often misleading.

The valuable work of Dr. Mott, however, has thrown new light upon the subject and helped to make clear that which was previously obscure. He has found that the basophile staining substance which forms the Nissl granules does not exist as such in the living cells, but is the result of coagulation. "If living cells are examined microscopically with dark-ground illumination they are seen to be filled with small granules or globules, each of which, after escaping from the cell, remains discrete.

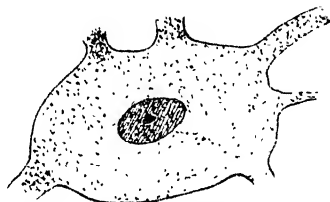


Fig. 101.—DRAWING OF AN ANTERIOR HORN CELL, WITH PROCESSES.
(After Mott.)

"They are refractile," says Mott. "and appear white and luminous ; this is due to a delicate covering film of a lipid substance which encloses a colloidal fluid, probably consisting of a solution of salts and cell globulins. When the cell dies this colloidal fluid is massed together in little blocks—the Nissl granules ; the intervening denser colloidal substance is continuous with the colloidal substance of the axon and dendrons. . . . It thus appears possible that these granules represent a large oxygen surface, like spongy platinum, within the cell. When the cells die, the lipoidal film of the globulin containing fluid is destroyed, coagulation occurs, and the Nissl granules are formed. These facts accord with the knowledge that stimulation of

a piece of nerve causes practically no metabolic change or using up of oxygen, therefore the mere conduction of a stimulus along a nerve does not entail loss of neuro-potential. The chemical processes incidental to the using up of nervous energy in the neuron take place in the cell itself, and 't is for this reason that the blood supply of the grey matter is six times that of the white matter."

All this, coming as it does from a great pathologist, is strongly in favour of the opinions I hold.

CHAPTER XIV

THE NODES OF RANVIER

IN these the axis-cylinder is invariably shown as passing in an uninterrupted course through the node, but although it is highly speculative and daring to say so, I doubt whether this is the case functionally, although we must believe it to be so anatomically. The following illustration is a typical one :—



Fig. 102.—MEDULLATED NERVE-FIBRE SHOWING FIBRILS OF AXIS CYLINDER (BETHE). The fibrils are seen passing, without interruption, across a node of Ranvier. (After G. N. Stewart.)

Now, these nodes occur at regular and innumerable intervals along the course of an axis-cylinder, but their function appears, so far as my reading goes, to be imperfectly understood. If, unlike their prototypes in the bamboo and the sugar-cane, the axis-cylinder is structurally continuous throughout its course, they do not seem to serve any useful purpose. If, on the other hand, there is a species of synapse at each node, their purpose and function

become at once apparent, for they would afford protection to the axon against extensive degeneration consequent upon injury.

Let us examine a node in a piece of bamboo.

According to Strasburger there is a wax incrustation, in the form of small rods, at *a, b*. The interior of the stem, between the nodes, is filled with a soft sponge-like substance which, while the plant is alive, transmits electricity—each internode indeed seems to bear some resemblance to a cell—so that the line *a, b*, notwithstanding the wax incrustation, does not involve a break of continuity. That being so, it would appear that the node is of the nature of a synapse, and that if the current is not inductively transmitted there is considerable added resistance at each node.

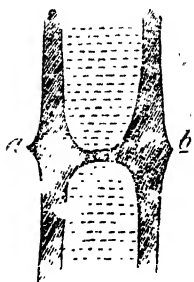


Fig. 103.

These nodes, be it remarked, occur at regular intervals upon the stems of bamboo (all canes) and sugar-cane, in much the same way as they do along the course of human nerves.

In the nodes of Ranvier the line *a, b* is absent, and it does not necessarily follow because a colouring matter like picro-carminine diffuses into the fibre only at the nodes, and stains the axis-cylinder red, while it does not diffuse through the white substance of Schwann, that there is any difference in the substance of the axon itself at those points.

But that there is a phase in the nature of a comparatively high resistance across the line *a, b* is, I think, more than probable; for this reason:—

When a nerve is severed, degeneration in the proximal segment takes place only as far as the first node of Ranvier.

Consider what, from an electrical point of view, that

may mean. Let us take two nerves, a motor and a sensory, and see what would happen if they were both severed in life.

In the case of the motor nerve the battery is in the brain with one pole to earth (air), while the nerve—the wire, as it were—is also to earth through tissue and skin.

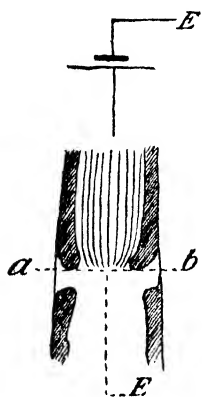


Fig. 104.

The effect of the cut is to remove the conductor, *quâ* conductor, below the node immediately above the cut and to an imaginary line *a, b* (Fig. 104). The whole of the apparatus above the line *a, b* would be structurally and electrically intact, and the line *a, b*, if of high resistance, would be equivalent, in hydrostatic parlance, to a ligature applied to an artery or a vein. Precedent to repair or regeneration of the lower portion, no muscle below the cut could receive an impulse.

If, however, the axis-cylinder were continuous through the node there would be a path of low resistance at the node—an escape of current into wet tissue—and the muscles above the cut could only receive stimuli at a greatly lowered pressure.

In a sensory path the need of a synaptic node is even greater, for the sensory nerves are closed circuits, and they have many ramifications in motor as well as other sensory paths over which they transmit impulses in various directions. To take a simple sensory path, however, from, say, skin to post-spinal ganglion.

Here we have a charged wire, a unipolar guard-cell or cells to maintain normal potential in that wire, and a receiving instrument in the cord. If the nerve were severed no impulse could be conveyed, but, given the line of resistance *a, b*, the upper part of the nerve from the first

node above the cut, together with the unipolar cells and receiving instrument, would be in working order, and only that portion of skin in connection with the lower part of the nerve thrown out of gear. If, however, there were no line of resistance at the node above the cut, all the circuits with which the nerve is functionally associated would suffer, the nerve and the cells lose their charge, and the receiving instrument would be left idle.

It is inconceivable, to my mind, that the resistance of the axis-cylinder is not greater, much greater, at the nodes than in the internodes, but as a matter of possibility this, instead of involving a change of material, may be created by constriction of the axon, as the effect of constriction in the course of a liquid conductor is to materially lower conduction at that point.

In some works the nodes are called "constrictions," and the suggestion is made that instead of the constriction being due to a tightening of the sarcolemma it is effected by a band (band of Ranvier) which compresses the axon. How this may be I do not know, but I am convinced that in whatever manner it is brought about there is condenser-action or similar cause of delay at every node.

CHAPTER XV

GANGLION CELLS

I HAVE stated elsewhere * that from an electrical point of view some ganglion cells are condensers and some storage cells, but this statement calls for elaboration. In telegraphy—and the brain, it is necessary to remember, both *sends* and *receives* messages—one of the functions of a condenser is to maintain electrical equilibrium, and, when required, to change the sign of current; whereas the function of a storage cell is to receive a charge and to hold it until some disturbance of neuro-electrical equilibrium calls for its delivery, either wholly or in part. In this connection let us consider ganglion cells with a view to attempting to differentiate the condenser pure and simple from the storage cell.

Condenser-ganglion cells should be studied more especially in relation to the sympathetic system, the nodes of Ranvier and the structure of the muscles, bearing in mind not only the change of sign, *i.e.*, from downward to upward current, or from efferent to afferent, but control of regularity of supply. Assuming there to be, for instance, a flow of nerve-energy of a certain potential from the brain (downwards) along, say, the sympathetic, the current strength would vary with the resistances in circuit in obedience to established laws, but it might be necessary to regulate both current strength and sign at different points of the circuit. Without condenser-action the current would have to reach a junction and return by a nerve-wire,

* *Electro-Pathology and Therapeutics.*

to change the sign from efferent to afferent, but that change could be more rapidly if not more effectively made if a condenser-ganglion cell of the proper capacity were inserted in position.

Let us assume that we had a downward or efferent current from the brain along the sympathetic—and the argument is not affected if we suppose an upward or afferent current to the brain—and it was required to take off at various points an upward current of varying strength. It might easily be done.

In the following diagram the thick vertical line is intended to represent the chain of the sympathetic—

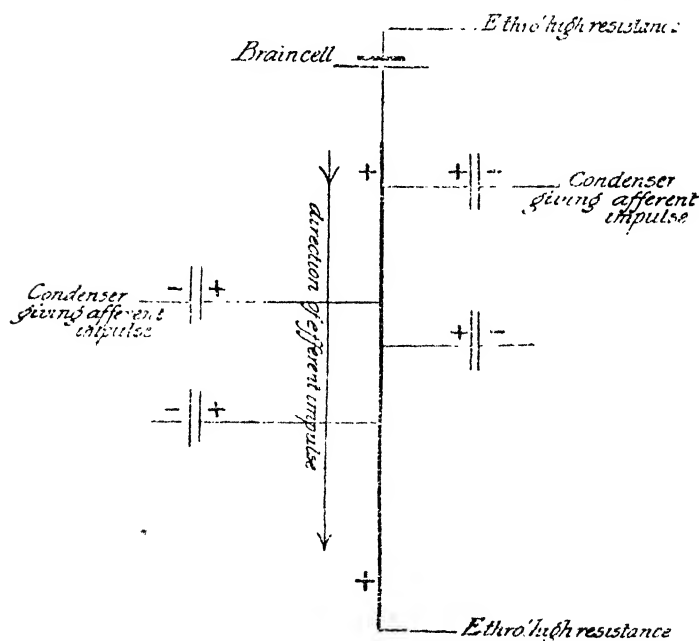


Fig. 105.

Except where a condenser is inserted the impulse from the brain would be efferent, and its current strength would

be subject only to Ohm's law, and the tension to the laws we have been discussing. If at any point it was desired to alter the sign again or to alter the tension, the insertion of another condenser-ganglion cell of the required plate-area in circuit would do it.

The diagrams on next page, Figs. 106, 107, illustrating the neurons of the motor path (after Halliburton), and a similar electrical arrangement, will further explain my meaning.

Study of the physiological diagram will show that, conforming as the body must do in its structure to established electrical laws, the source of energy, *i.e.*, the cell of the cerebral grey matter, is to earth (in this case air) in the same manner as the battery in the electrical diagram, while every muscular fibre is to earth (air) through the skin. If it is desired to make a large low-tension motor-cell multipolar, and to transform the tension therefrom upwards, it is only necessary to provide it with one, or more, additional arborisation, linking by induction with one or more condensers of the type of *b*.

Judging by their effects, we might believe that quantity and tension constitute two very different elements. They are in reality but two forms of the same thing. The transformation of quantity into tension results simply from the mode of distribution of the same energy. We realise the transformation by concentrating the energy within a very small space, which amounts to raising its level above that of the zero of energy. The converse operation will transform, on the contrary, tension into quantity. A coulomb spread over a sphere of 10,000 kilometres radius will give only a pressure of one volt. Let us spread the same quantity of electricity over a sphere of a diameter 100,000 times less—that is to say, of 100 metres—and this same quantity of electricity will produce a potential a hundred thousand times higher—that is to

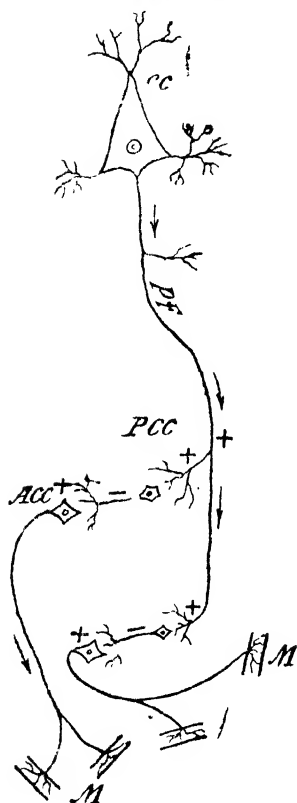
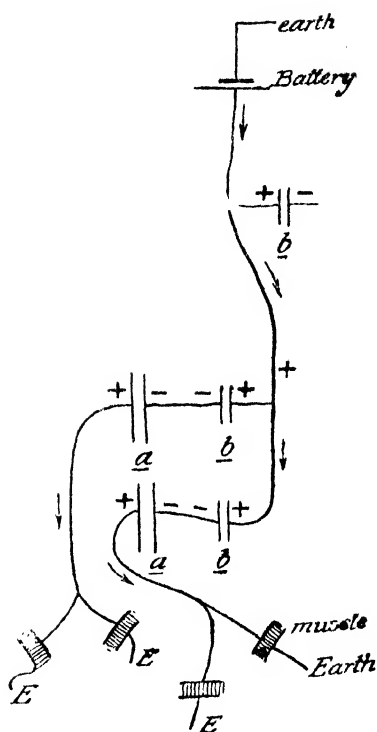
Physiological.*Electrical.*

Fig. 106.

(After Halliburton.)

Fig. 107.

PCC = small cells at the base of the posterior cornu.

ACC = large motor-cells of the anterior cornu.

M = muscular fibres.

PF = axon.

CC = cell of the cerebral grey matter.

aa = low-tension condensers.

bbb = high-tension condensers.

say, a pressure of 100,000 volts. The quantity of energy expended has not been varied, only its distribution altered. (Le Bon.)

In this light we may ponder several forms of spinal ganglion cells, showing the cell bodies, the afferent sensory nerves, and the dorsal roots.

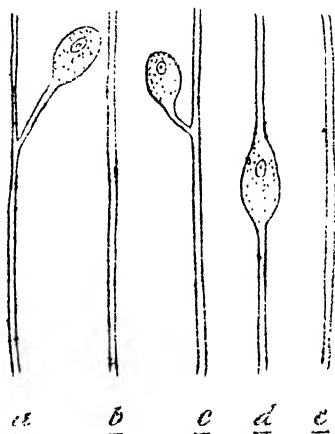


Fig. 108.

(After Landois and Stirling.)

To my mind *a*, *c* are nerves carrying storage cells, which would hold their charge unless and until excessive mental or physical exertion had disturbed neuro-electrical equilibrium in the sense of bringing about a subnormal local or general body potential. while *b* and *e* are simple closed circuits, and *d* a nerve carrying a condenser. Perhaps this view may throw some further light upon the subject and help us to a better appreciation of the functions of ganglion cells. It must be remembered, however, that the due functionment of both ganglion storage and ganglion-condenser cells is absolutely dependent upon the maintenance of their normal insulation resistance. Should the absolute insulation of the storage cell be broken down

to any extent there would be defective storage, and if the resistance of the insulating membrane in the condensing cell were broken down or altered there would be a "fault."

In works upon Physiology confusion is caused by the uncertainty which attaches to the meaning of the words "stimulus," "impulse," "irritation," and "charge" when applied to nerve cells, but if it be accepted that the natural impulse is neuro-electrical, and that the changes which take place in nerve-cells and processes are due to alteration of nerve potential, sign of nerve current, or variations of external or internal resistance, a clearer appreciation of the laws which govern the nervous system may be obtained.

In the same way we may find an explanation of unipolar, bipolar, and multipolar cells. The storage-ganglion would be unipolar and the condenser-ganglion bipolar, while a cell provided with two or more sets of alternately conducting and insulating materials would naturally be multipolar. Unfortunately the illustrations to be found in works upon Physiology are not designed to show the electrical structure of nerve cells and processes, and therefore the difficulties in the path of the student are great. That there is no book upon Biology or Botany which gives any information upon the electrical structure of any inhabitant of the vegetable kingdom is no longer to be wondered at when some of the higher forms of life are little understood. And yet, once the eye has been taught to observe, that electrical structure is so clearly evident that the most remarkable thing about it is the obscurity in which it has remained.

Some further light is thrown upon the function of the storage-ganglia by the electro-cardiograms given by athletes after strenuous physical effort has exhausted their reserves. Nature has to generate nerve force to supply the immediate requirements of the body, and as part of this is, and must

be, taken up by the storage-ganglia to replace the charge given out by them, the process of recovery, as shown by the string galvanometer, is slow. The hypothesis, therefore, that the ganglion cells receive "charge" and not "irritations" seems to be tenable. In Thornton's *Human Physiology* we are told that by a *nerve-centre* we must understand a ganglion cell, or group of cells, capable of receiving, *modifying*, and discharging nerve impulses, and thus acting for the performance of some function. As I have explained it, this is intelligible. Reject that explanation and no *one* law remains to account for all the phenomena. There can only be one law, and that law applies with equal force to both the animal and vegetable worlds. Every observed phenomenon must be in harmony with it, if the observer is not in error.

Turning again to Thornton, the following passage is worth quoting : " Experimental excitation shows that the anterior root " (of a spinal nerve) " contains efferent fibres and the posterior afferent fibres. . . . Other fibres pass by these cells and do not appear to be connected with them. What their nature is cannot yet be stated." All this is consistent with condenser-action, and may be explained by it. What appears to be required is that the specialist physiologist should collaborate with the specialist electrician in the study of the human nervous system, and I think this will have to be done if appreciable progress is to be made during our lifetime.

" Upon the object of autonomic ganglia I can find nothing which conflicts with the views I hold. . . ." Nature has, as it were, before her the problem of supplying with nerves the vast mass of muscles in the body, and the space at her command in the various exits from the cranium and spinal canal does not allow of more than a comparatively small outflow from the central nervous system.

" The difficulty is met to some extent by the branching

of the out-flowing nerve-fibres, and in the case of the voluntary muscles this appears to be sufficient. The most striking example of this can be seen in the electrical organ of the malapterurus, where the millions of its subdivisions on each side of the body are all supplied by the branches of a single axis-cylinder process originating from a single giant nerve-cell in the brain.

“But in the case of the involuntary muscular tissue there is an additional means of distribution, for each fibre that leaves the central nervous system arborises around a number of cells in the autonomic ganglia, and thus the impulse is transferred to a large number of new axis-cylinder processes. . . . The afferent or sensory fibres are much less numerous than those which are efferent. . . . Thus in the splanchnic and hypogastric nerves about one-tenth of the fibres are found to be sensory, and in the pelvic nerve about one-third of the total fibres are sensory.” (Halliburton, 1915.)

UNIPOLAR AND BIPOLAR NERVE CELLS.

Unipolar cells, as I have stated, are, in my view, storage cells, and appear to be prominently associated with the closed circuits of the sensory nerves. In common with other nerve-cells they contain at least one conducting substance in organically combined iron (Macallum), and non-conducting substances, possibly the *deep* and *superficial reticula* described by Golgi and regarded by J. Turner as investments derived from neuroglia cells. However that may be, I am constrained to the opinion that in all nerve-cells we have a form or forms of condenser or Leyden jar; that is to say, they may consist of one or more jars, and that, if more than one, these elements may be connected in series or in parallel, for the regulation, adjustment, and distribution of tension.

The best illustrations I have been able to find are given in Schäfer's *Essentials of Histology*, and I reproduce them in the hope that the apparently electrical structure may stimulate further research and pave the way to their explanation in electrical as well as in physiological terms.

Before doing so, however, we may usefully remember that "in the ganglia each nerve-cell has a nucleated sheath which is continuous with the neurilemma of the nerve-fibre with which the cell is connected; that in the spinal ganglia the axis-cylinder process divides into two within the ganglion, one fibre passing to the nerve-centre and the other towards the periphery; while in the sympathetic ganglia the nerve-cells usually have several dendrons and one axon."

Furthermore, "the cells of ganglia are disposed in aggregations of different size, separated by bundles of nerve-fibres which are traversing the ganglion. The latter, if large, is inclosed by an investing capsule of connective tissue which is continuous with the epineurium and perineurium of the entering and issuing nerve-trunks." (Schäfer.)

A peculiarity which should not be lost sight of is that in the spinal ganglia and in many of the corresponding ganglia on the roots of the cranial nerves of mammals the only issuing process is the axon, and when this divides into two the branching is T-shaped or Y-shaped, and *always occurs at a node of Ranvier*; the neuro-fibrils of the central and peripheral branches retaining their individuality in the common trunk and being traceable into a neuro-fibril network within the cell body.

And now, having collated these facts, let us remember that *an electrified ball exhibits the same tension on every part*, and see how this physical law agrees with the theory of neuro-electrical cell-action, taking into consideration that, while every cell in the body may be, in a sense, a condenser, transmitting neuro-electrical impulses in various directions

and with varying tension, every cell is not of the same structure or designed for the performance of the same function. We must, therefore, examine them in detail and have special regard to their formation, so far as it has been made clear, or can be said to be suggestive to the electrician.

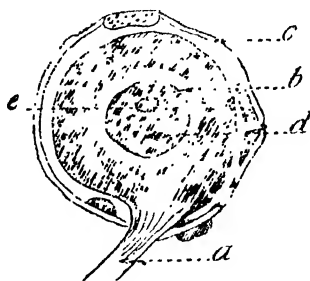


Fig. 109.

UNIPOLAR CELL from spinal ganglion of rabbit. *a*, axon; *b*, circum-nuclear zone, poor in granules; *c*, capsule; *d*, network within nucleus; *e*, nucleolus. (After Schäfer.)



Fig. 110.

BIPOLAR CELL (ganglion) of fish (Holmgren). It will be noticed that the medullary sheath is continued as a thin layer over the cell-body. (After Schäfer.)

MULTIPOLAR CELLS.

So far, the cells appear to be more or less globular in shape, and while the multipolar cells of the cerebral cortex and spinal cord appear to differ materially, as a whole, from those of the unipolar and bipolar type, they must obey the law, and therefore possess, although perhaps in a modified form, the same internal arrangement or arrangements and similar absolute capsular insulation.

To the electrician the construction of a multipolar cell to transmit efferent and afferent impulses would be a comparatively simple matter. Take two hollow metal

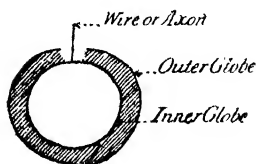


Fig. 111.

globes or ellipses or modifications of either, place one inside the other in such manner that there is an air-space or insulating layer between them, and drill a hole in the *outer* globe to receive an insulated wire, which would make metallic contact with the *inner*

globe (Fig. 111). The next step would be to solder a number of insulated wires to the outer globe, and to then provide absolute insulation for the whole by coating the outer globe with, say, gutta-percha solution or Chatterton's compound.

Now, in a Leyden jar the inner and outer coatings are metallic, the glass walls of the jar form the dielectric substance, and discharge is prevented by the resistance interposed by air intervening between the outer coating and the earth. In the human body all the nerves are to earth, through the air, and the resistance of that intervening stratum of air is sufficiently great to prevent discharge, *under normal conditions of charge*, taking place prematurely. When, however, a motor or secretory nerve receives an efferent impulse, or it may be impulses, the added tension is just enough to bridge the spark gap, as it were, and so to permit of a discharge or partial discharge.

It will be seen, however, that the surface area and therefore the tension of the two globes, as sketched in Fig. 111, is not the same, and that if the impulse conveyed by the axon were an *efferent* impulse all the wires connected to the outer globe would transmit lower-tension *afferent* impulses, in which case the cell would not be multipolar.

But in the majority at least of these cells there are

branch circuits, collaterals, or dendrons (corresponding to our wires of the outer globe) which terminate in arborisations or end-organs, connecting, interlacing, or intermingling with other nerve-cells, of which they are anatomically independent. These other cells and arborisations act, as I have endeavoured to show, as condensers in changing the *sign* of current or impulse, and, as I have suggested, any variation of tension may be brought about by varying the area of the condenser-plates, discs, or points, or conducting cell areas.

In the typical multipolar cells of the spinal cord, as shown by Max Schultze, only one process becomes the axis-cylinder of a nerve-fibre, the others breaking up into arborisations of *fibrils* which can be traced into the axon and the other branches of the cell. "Between the fibrils the protoplasm of the cell contains a number of angular or spindle-shaped masses . . . known as *Nissl's granules*" (see p. 189). "These nerve-cells often contain . . . granules of pigment, usually yellow, the nature of which has not been determined." As a matter of possibility, the yellow pigment may be an insulating substance of the nature of elastin, but as to this I am not, in the absence of any definite information as to its chemical composition, able to offer an opinion.

We may now compare a multipolar ganglion cell as illustrated physiologically with the artificial contrivance before mentioned. (Figs. 112, 113.)

Supposing an efferent impulse to be conveyed to the inner globe, as shown in the electrical diagram, all the discharge impulses would be afferent, and, as I before remarked, the cell would not be multipolar. A condenser of suitable capacity inserted between any one or more of the terminals *c, d, e, g, h, i, j, k*, would retransform the impulse from afferent to efferent, and either raise or further lower the tension in accordance with its surface area,

Physiological.

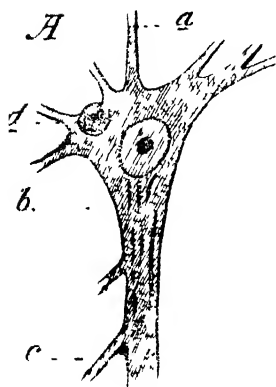


Fig. 112.

Electrical.

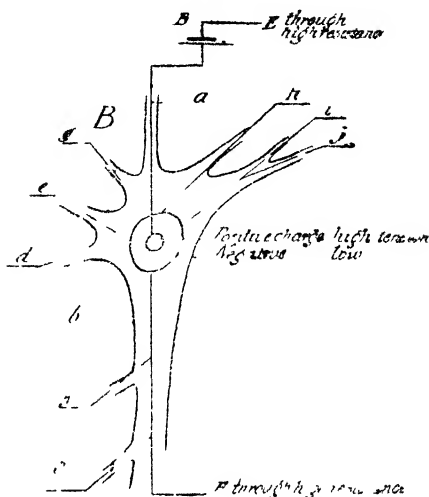


Fig. 113.

(After Schäfer.)

PHYSIOLOGICAL A, large pyramidal cell of cerebral cortex, human. Nissle method (Cajal). *a*, axon; *b*, cell body; *c*, apical dendron, *d*, placed between two of the basal dendrons, points to the nucleus of a neuroglia cell; diagram reversed. Seven other branches, presumably dendrons, or collaterals, are shown and these must interlace, by means of their arborisations, with other cells.

ELECTRICAL B, battery, *a*, axon or line-wire, *b*, insulating cover or capsule; *c*, *d*, *e*, *g*, *h*, *i*, *j*, *k*, branches from outer globe.

while, if it was desired to retain an afferent impulse at any point, no condenser would be inserted at that point. Physiologically, of course, the dendrons would inductively connect with neighbouring cells by means of their arborisations; electrically the condensers, when inserted, would be connected more or less as shown in Fig. 114.

It is quite evident, however, that this explanation of the functioning of a multipolar cell is insufficient. Supposing the inner and outer globes to act as a Leyden jar, all the impulses, efferent and afferent, would be conveyed simultaneously with each discharge, and while Nature does not waste any impulse but utilises it in the motor, secretory,

and some sensory paths, it seems to me improbable that action takes place in the manner I have described. Even if the branch circuits or collaterals, with their inductive effect upon cells contiguous to them, were of different resistance and the cells of varying capacity, the impulses would still be simultaneous, though varied as to tension. We must therefore, I think, come to the conclusion that

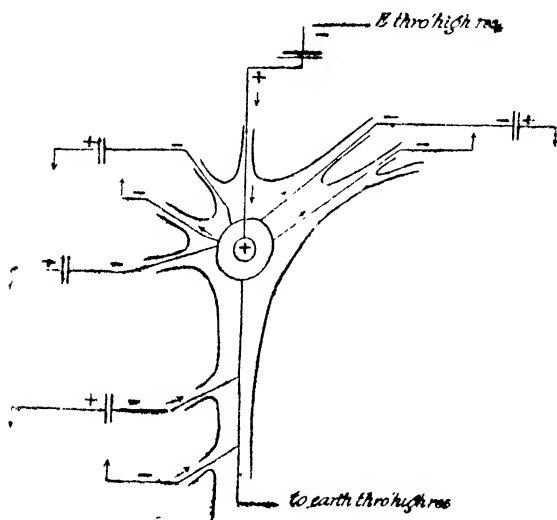


Fig. 114.

Diagram, showing how an artificial multipolar cell circuit might be arranged to give any number of efferent and afferent impulses.

instead of a multipolar ganglion cell being made up of one Leyden jar with multiple connections, it is made up of many such jars or rings, and that the axis-cylinder process divides, not into two, but into as many independent or, in other words, insulated fibres or fibrils as there are collaterals, and that each of these fibrils leads to a separate, though perhaps not anatomically distinct, condenser or jar, and, inductively, through that jar to the dendron designed to convey a specific impulse, efferent or afferent.

I am encouraged in this opinion by a careful study of the structure of unipolar cells and by other considerations. To my mind it would appear that the structure of even the unipolar cell is not simple but complex. It seems to be circular in form throughout—to be, in fact, a series of rings ; and while the microscope has not, so far, given us the needful detail, it does not call for an undue stretch of the imagination to believe that it may, possibly, be composed of a series of Leyden jars ; that is to say, circular layers of conducting substances with non-conducting substances between them, and that such layers, like the sarcomeres, are insulated from each other and are in connection with certain assigned nerve-fibres or fibrils. In such case we can conceive in a multipolar cell the impulse being given, as a whole, from a principal central system, or, individually, to any dendron or branch circuit.

Since writing the foregoing my attention has been drawn to an illustration in Haeckel's *Evolution of Man* (taken from Max Schultze) of a multipolar cell from the brain of an electric fish, and as it seems to confirm my theory I reproduce it. (Fig. 115.)

Reverting to the typical multipolar cell of the spinal cord, and at the risk of repetition, I must remind my readers that the axis-cylinder process itself invariably gives off side branches or collaterals, which pass into the adjacent nerve-tissue. "The axis-cylinder then acquires the sheaths, and thus is converted into a nerve-fibre. This nerve-fibre sometimes, as in the nerve-centres after a more or less extended course, breaks up into a terminal arborescence enveloping other nerve-cells ; the collaterals also terminate in a similar way . . . all ultimately terminate in an arborescence of fibrils in various end-organs (end-plates, muscle-spindles, etc.)."

Furthermore, "each nerve-unit (cell, plus branches of both kinds) is anatomically independent of every other

nerve-unit. There is no true anastomosis of the branches from one nerve-cell with those of another, and nerve impulses are transmitted from one nerve-unit to another,

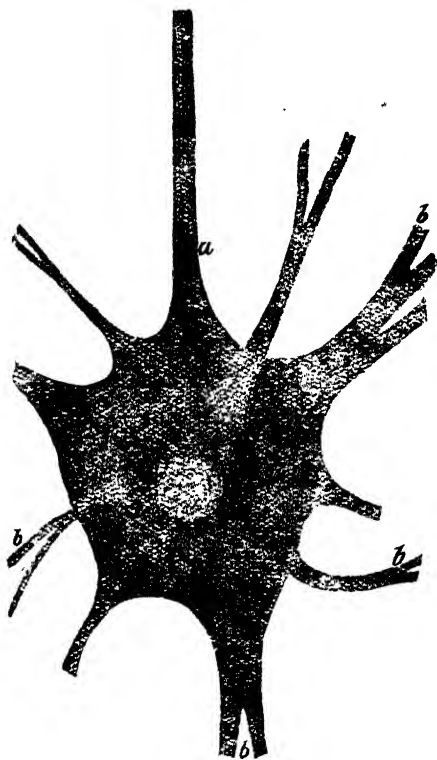


Fig. 115.

A LARGE BRANCHING NERVE-CELL, from the brain of an electric fish (*Torpedo*), magnified 600 times. In the middle of the cell is the large transparent round *nucleus*, one *nucleolus*, and, within the latter again, a *nucleolinus*. The protoplasm of the cell is split into innumerable fine threads (or fibrils), which are embedded in intercellular matter, and are prolonged into the branching processes of the cell (*b*). One branch (*a*) passes into a nerve-fibre. (From Max Schultze.)

through contiguous but not through continuous structures.”
(Halliburton.)

The following illustration is given to explain reflex action :—

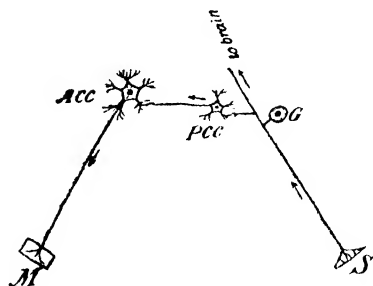


Fig. 116.—REFLEX ACTION. (*After Halliburton.*)

Excitation occurs, we will say, at a sensory surface S, and the impulse is transmitted by the sensory nerve-fibre to the central nervous system. "This fibre does not become anatomically connected to any of the cells of the central nervous system. The only cell-body in actual continuity with the sensory nerve-fibre is the one in the spinal ganglion (G)" (a storage cell). "On entering the spinal cord the main fibre conveys impulses upwards which ultimately reach the brain, but in the spinal cord it gives off fine side branches or collaterals which terminate by arborising around one or more cell-bodies and their dendrons; these cells are small ones situated in the posterior cornu of the spinal grey matter; one only (PCC) is shown in the diagram. The short axon of this cell similarly terminates by a synaptic junction with one or more of the large multipolar cells of the anterior cornu of the spinal grey matter; one of these shown in the figure is labelled ACC. This motor cell is thus stirred up to action and sends an impulse by its axon to the muscular fibres it supplies." (Halliburton.)

I may remark, in parenthesis, that we have here evidence of condenser-action, of cells changing the sign of

current and transforming, in a shunt-circuit, an afferent to an efferent impulse. The correct number of cells is not shown, but any *even* number between G and ACC or any uneven number between the sensory nerve-fibre and the motor fibre would do it.

Halliburton avers that : "*The synaptic junctions are naturally the places which the impulse has the greatest difficulty in traversing ; and some observers believe that at the points of contact there is a kind of undifferentiated interstitial protoplasm which the impulse has to get through.*" *

Suppose there to be many thousands of such synaptic junctions, or, electrically speaking, many thousands of condensers of varying capacity, concentrated over a length of, say, three feet, and further suppose them to be ultimately connected to a copper wire of three feet in length to earth through a high resistance at its further end. Let the condenser-length be from A to B and the wire-length from B to C. Would the velocity of a current of electricity sent from A to B be the same as from B to C ? Obviously it would not, could not, be.

Going back, after these interpolations, to our diagram of reflex action, the electrical impulse, due to alteration of resistance at S caused by, for instance, a rise or fall of temperature, by pressure upon the skin, etc., would be afferent. Upon reaching the storage cell, G, it would be affected or unaffected by difference or non-difference of potential between sensory nerve-fibre and cell. If the cell held its normal charge, the impulse would pass unaltered (by that cell) on its path to the brain. If, however, the potential of the cell was higher than that of the fibre, the impulse would be increased or accelerated, and *vice versa*. At the point PCC, the cell there would be in an inductive

* The italics are my own and are intended to suggest a reason, one reason, for the comparatively very low velocity of the nerve-current as compared with that of electricity along a wire or cable.

shunt-circuit, and would transform some portion of the afferent impulse to an efferent one, *should no other cell be between it and the muscular fibre*. The multipolar cell, ACC, being interposed, it follows that one cell between the sensory nerve and the muscular nerve-fibre is omitted in the diagram.

“For a reflex action,” remarks Halliburton, “three things are necessary : (1) an afferent nerve, (2) a nerve-centre consisting of nerve-cells to receive the afferent impulse and send out the efferent impulse, and (3) an efferent nerve along which the efferent impulse may travel.”—*Verb. sap.*

I have said that in my view unipolar cells are of the storage type and appear to be prominently associated with

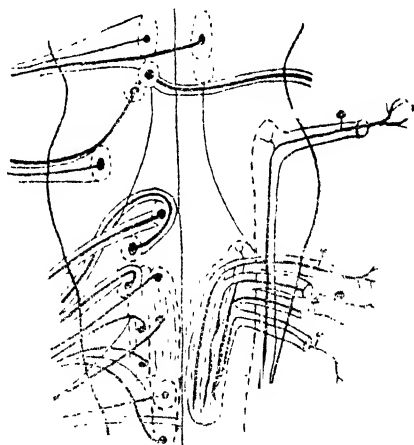


Fig. 117.

Shows on the left the motor nuclei and efferent fibres, except those of the fourth nerve, and on the right side the afferent fibres. (*After Schäfer.*)

sensory nerve-fibres ; their function, mainly if not entirely, being to maintain equilibrium in a closed-circuit system.

In this connection there are at least two diagrams in Schäfer's *Essentials of Histology* which support my view,

and I am of opinion that if we had a complete plan of the nervous system, showing the whole of the efferent and afferent nerve-fibres and all the intervening cells, with their arborisations, so that the different circuits could be traced, my contention as to condenser-action in the body would be more than amply justified.

The first of the diagrams to which I have referred is given in the chapter upon the Medulla Oblongata, and is intended to illustrate the origin and relations of the root-fibres of the cranial nerves (Fig. 117).

There is a further diagram of the efferent fibres only, but no unipolar or storage cell appears.

The second diagram to which I have alluded is given in the chapter upon the Pons Varolii, and is a plan of the origin of the fifth nerve :—

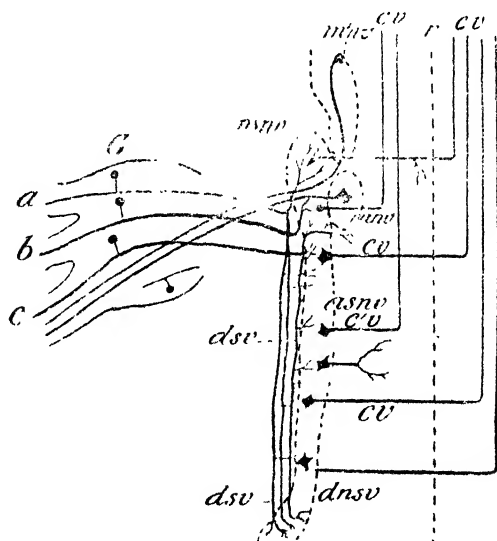


Fig. 118.

G, Gasserion ganglion ; a, b, c, three divisions of the nerve ; m'nv, superior motor nucleus ; m'nv, principal motor nucleus ; p'snv, principal sensory nucleus ; asnv, d'nsv, descending sensory nucleus ; d'sv, descending root ; cv, c'v, central sensory tracts composed of fibres emanating from the sensory nuclei ; r, plane of the raphe. (After Schäfer.)

The fifth or trigeminal nerve, it is scarcely necessary to remark, emerges at the side of the pons in two roots, a small motor and a large sensory, and it is only in connection with the sensory nerve that we find the spherical unipolar cells associated. The motor root, as one might expect, is provided with numerous multipolar cells, so that it cannot be said to be entirely distinct from the larger posterior sensory root with which it emerges, inasmuch as any branch of it can be made afferent, although not sensory in the sense of a closed circuit, by the insertion of a bipolar cell between a motor nerve-fibre and a branch.

Before concluding this study I should like my readers to take careful note that in the course of voluntary motor fibres, before they pass into the anterior root (spinal cord) they always first form connections with the multipolar nerve-cells of the anterior cornu, which, in fact, are introduced into the course of the conducting-paths; but, in their passage through the brain, the paths for direct motor impulses are not interrupted anywhere in their course by ganglion cells, not even in the corpus striatum or pons. They pass in a direct uninterrupted course.

CHAPTER XVI

THE EYE AND THE EAR

THE EYE

IF I shrink from giving a detailed description of the manner in which I believe these two organs of special sense operate, it is not because the task is beyond me, but because, owing to my limited knowledge of histology and the paucity of information—as regards the neuro-electrical ramifications of the circuits—for my enlightenment, I grudge the time that would have to be spent in further research; whereas a physiologist who could bring himself to ponder the matter from a purely electrical, or rather from a purely telegraphic and telephonic point of view, would, I have no doubt, be able to do the subject greater justice.

At the same time, it is incumbent upon me to put upon record my opinion that the eye is strongly suggestive of a compound selenium-cell transmitting apparatus, and that the ear does not differ in any essential respect from a telephone system, the outer ear being the receiver, the middle ear the microphone, and the auditory nerve the line wire or wires to the brain.

The element called selenium is not very well known outside the precincts of the laboratory. It was discovered in the year 1817 in the refuse of a sulphuric acid manufactory in Sweden by Berzelius, and is obtained in two forms, one of which is soluble in carbon disulphide, the other being insoluble in the same medium. The first

is of a reddish-yellow colour, conducting heat badly and electricity not at all, while the other variety—known as black or metallic selenium—conducts heat, and under certain conditions will form a good conductor of electricity. It is with the latter only that we are concerned.

In 1873 Mr. Willoughby Smith, then electrician-in-chief to the Telegraph Construction and Maintenance Company, discovered that this substance had a peculiar property in that its electrical resistance varied with the amount of light to which it was subjected; the difference in these variations being very marked, and in the inverse ratio to the degree of light. Later on Dr. Siemens, Professor Adams, the Earl of Rosse, and other scientific men took up the subject, but nothing practical was done until Professor Graham Bell, in association with Mr. Sumner Tainter, produced the photophone, an instrument in which light was utilised for the transmission of sound.

Of more interest to us, however, is the “Selenium eye” of Dr. Siemens. It was in reality an artificial human eye, with a lens in front, and lids to close when it was weary; for, curious as it may seem, it, like its perfect prototype, became tired when exposed for a prolonged period to bright light.

The lens caused any light to which the “eye” was subjected to be concentrated in the interior of the eyeball, and at this spot a selenium grating was placed. This was composed of two fine wires running together in zigzag fashion, but not making actual contact. Upon these was placed a melted drop of selenium, and the ends of the wires were joined up with a galvanometer and battery. When the “eye” had been closed and at rest for some little time, it was found to be sensitive to the faintest gleam of light, but after long exposure to bright light the lids closed for a long time before it became again sensitive to feeble rays.

Since then much experimental work has been done, and

inventions of scientific interest but no great commercial value have resulted.

One of the most successful attempts—the invention of a Pole named Szczepanik—to transmit pictures to a distance by the agency of selenium was described in *Pearson's Magazine* of October, 1899, by Mr. Cleveland Moffett. It was called the "Telectroscope," and was founded upon the fact that any vision or image produced upon the retina is only the blending together of an infinite number of points projected separately from the object and seen by separate rays of light. Some of these come a fraction of a second later than others, but if the intervals between them be short enough persistence of vision will have the effect of bringing them together and forming a complete picture.

From the article in question I gather that Szczepanik devised a way of separating any image formed by an ordinary photographic lens into its component luminous points, of transmitting these points separately, but with enormous rapidity, over wires, and letting the eye reconstitute them at the other end into the original picture.

Selenium, it may be said, possesses the peculiar property of transforming waves of light into waves of electricity, so that if rays of light are thrown upon a selenium disc to which insulated wires are connected, it will be found that currents are set up in the wires, and moreover that rays of light differing in colour and intensity give rise to currents which also differ in intensity; each particular ray having its corresponding current, and no two of them being exactly alike.

Szczepanik's transmitting apparatus consisted of a box with a camera front and a photographic lens for focussing an image outside the box upon two vibrating mirrors, designed to resolve the image into points and project these upon a selenium disc connected by wires with the receiving

apparatus. The transmitting wires terminated in two vibrating metal plates, contained in another enclosed box with a camera front, and these plates, by an ingenious method of lighting, allowed a changing band of light, as thin as a hair, to pass between them. This was broken up in turn by two other vibrating mirrors and projected upon a ground-glass plate, upon which the transmitted image appeared.

The inventor solved the problem of the conveyance of colour by passing the rays of light received by the lens in the transmitter and from the vibrating metal plates of the receiver through a prism, each ray being deflected more or less and each having an individual deflection; a violet ray being deflected more than a yellow ray, and a red ray less than a green one, and so on.

With the technical details of the Telectroscope we need have no further concern. Its interest, to me, lies not in the mechanical details—they were necessitated by the fact of there being only one selenium disc in the transmitting apparatus—but in certain curious points of resemblance to the human eye.

If, instead of one transmitting disc and two connecting wires, an infinite number of such discs and wires could have been employed, there would have been no occasion for the vibrating mirrors, for the reason that the "points" projected separately from the object would be received upon a large number of discs and conveyed to the brain by a large number of wires or nerve-fibres. The number of fibres in the optic nerve is said to be upwards of 500,000, while the number of cones in the rod and cone layer of the eye of man—the nerve-epithelium of the retina—has been estimated at 3,000,000.

It does not follow that these discs and wires are as multitudinous as the points of light which in their entirety form a picture or an image. It is because they are not so.

I take it, that there is such a thing as memory of the eye, or persistence of vision.

Comparing the lens of the eye with that of a camera, the iris is the diaphragm to regulate the aperture, and the rays or points of light admitted by the lens are thrown, although not directly, upon a layer of pigment cells which form the outer or choroidal surface of the retina.

It should also be noted that posteriorly to the iris is a layer of pigment cells, a continuation forwards of the pigment layer of the retina.

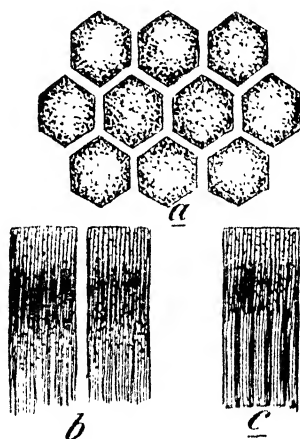


Fig. 119.—PIGMENTED EPITHELIUM OF THE HUMAN RETINA. (*Maschultze*.)

a, cells seen from the outer surface with clear lines of intercellular substance between; *b*, two cells seen in profile with fine offsets extending inwards; *c*, a cell still in connection with the outer ends of the rods.

In colour these pigment cells appear to be dark brown, and, like the macula lutea, apart from the fovea centralis, non-actinic.

It will be seen, from *b* and *c*, that fine offsets or nerve-fibres extend inwards from these cells, and, presumably, either make connection with or influence the rods and cones in their immediate vicinity; these rods and cones

connecting by means of various nerve processes and ganglionic cells with the brain.

“ At the fovea each cone is connected to a separate chain of neurons, whereas in other regions the rods and cones are connected in groups to these chains. . . . At the exit of the optic nerve the only structures present are nerve-fibres. . . . The nerve-cells in the retina remind us that the optic, like the olfactory nerve, is not a mere nerve, but an outgrowth of the brain.” (Halliburton.)

The clearest, if not the most comprehensive, exposition of the structure and functioning of the eye, so far as my reading goes, is contained in Thornton's *Human Physiology*. Briefly summarising this, I learn that the outermost layer of the retina next to the choroid consists of a single stratum of hexagonal epithelium containing black—but, according to Schäfer, dark brown—pigment. They are present in all parts of the retina, except at the entrance of the optic nerve. The outer surface of the cells is smooth and flat, but the inner part is prolonged into fine processes which extend between the rods. About 7,000 cones are said to exist in the fovea. Near the macula lutea the retina contains one cone to four rods ; midway to its termination at the ora serrata one cone to twenty-four rods ; at the peripheral part rods only.

Visual impulses begin in the rods and cones on the outer side of the retina, after the rays of light have passed through most of the retinal layers, and the processes started in these sensory epithelial cells of the retina pass back to the layer of fibres on the inner surface of the retina and thence by the optic nerve to the brain.

We know that the retinal vessels are distributed in the inner layers (nerve-fibres and ganglionic cells) of the retina, and the shadows cast behind them must be perceived by *something posterior to those vessels*. This is a clear proof, it is said, that the *external layers of the retina nearest*

the chorioid, that is, the rods and cones, are the elements in which the visual impressions begin.

"It thus appears that the real end-organs of vision, the rods and cones, must be in some way connected functionally, if not structurally, with the nerve filaments that pass to the optic nerve, and it is evident that these rods and cones, being backwards from the light towards the sclerotic, must receive the light waves after they have passed through the internal layers of the retina except at the fovea where, all the other layers having thinned off, the basal fibres of the cones themselves are directly exposed to the light waves." (Thornton.)

Before we accept the above conclusions as final it will be well to ponder the matter carefully.

There are several points which call for consideration. Cones are absent in some animals and rods in others. Light produces changes in pigment, but while the outer limbs of the rods are tinged with a pigment termed "visual purple," derived from the pigment cells of the outer layer of the retina, it can hardly be essential to vision, as it is "absent from the cones of the fovea and entirely wanting in some animals that see well."

I am not going to suggest that the epithelial pigment cells of the retina contain selenium, but I do suggest that they are composed of or contain some substance which has the property of transforming waves of light into waves of neuro-electricity, possibly by causing enormously rapid alterations of resistance in the sensory nerve-circuits connected functionally, if not structurally, with the cells.

"We do not know," says Thornton, "how the undulations of light become converted into nervous impulses that give rise to visual sensations."

The three following diagrams (Figs. 120, 121, 122) may with advantage be considered in their relation to the known optical law that "ordinary light consists of vibrations

taking place always in planes at right angles to the direction of the ray, but in all directions in those planes. That is, if the ray travels along the axle of a wheel, the vibrations composing it are all in the plane of the wheel, but are executed along any or all of the spokes." (Gordon's *Electricity and Magnetism*.)

Rays of light, entering at the lens, would, if the lens were a fixed object, approximate to the axle, and the rods and cones to the spokes of the wheel. But the lens is not a fixed object, as in a camera. It not only receives rays of light from above, below, and each side, but continually shifts its angle of reception of such rays by movement of the eye.

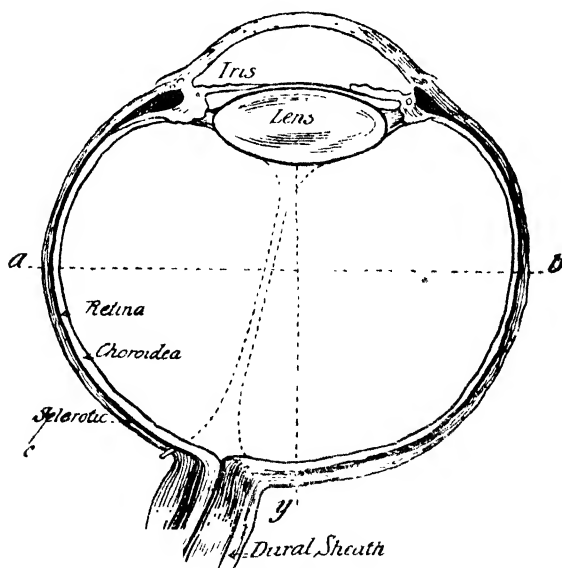


Fig. 120.

Diagram of a section through the (right) human eye passing horizontally nearly through the middle. *a, b*, equator; *y*, optic axis. (After Schäfer.)

The pigmented cells of the outer or choroidal surface are not shown in Fig. 121, but are illustrated by Schultze in a diagrammatic section of the human retina (Fig. 122).

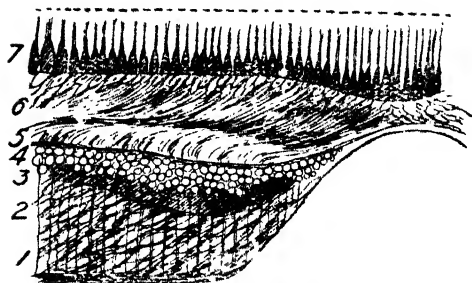


Fig. 121.

Vertical section through the Macula Lutea and Fovea Centralis; diagrammatic. (Thornton, after M. Schultze.)

1, nerve layer; 2, ganglionic layer; 3, inner molecular, 4, inner nuclear, and 5, outer molecular layers; 6, outer nuclear layer, the inner part with only cone fibres forming the so-called external fibrous layer; 7, cones and rods.

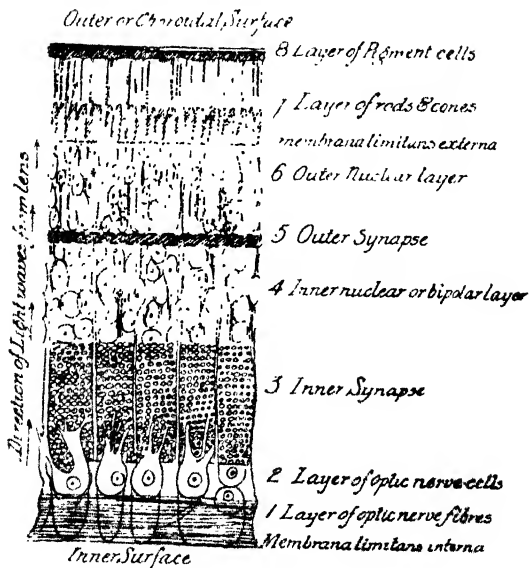


Fig. 122.—DIAGRAMMATIC SECTION OF THE HUMAN RETINA. (After M. Schultze and Schäfer.)

From the two previous diagrams it will be seen that, as in Szczepanik's apparatus, the rays of light are broken up and deflected at various angles before they reach the pigmented cells or the rods and cones, and I assume that, having arrived at, as it were, a terminal, they are, at that terminal, transformed into waves of neuro-electricity, which, picked up by the rods and cones, are conveyed in that form to the brain.

If something of that kind does not occur we are confronted with another very extraordinary coincidence.

In the *Science of Light*, by Percy Phillips, D.Sc., it is said : " If we suppose that the sensation of light is due somehow to the vibrations of electrons in the retina, the retina itself will do instead of a prism for drawing out a pulse into waves, and so we may have interference even without the prism. We see, therefore, that it is just as simple to imagine that the regular trains of waves are produced by the receiver as by the transmitter of the wave. We only need assume regularity of period in one or other of them."

The theory that the sensation of sight is due to the direct action of the vibrations of electrons in the retina calls for examination. It has not been finally and conclusively proved that light consists of short *electro-magnetic* waves. The strongest argument in its favour is Maxwell's calculation that the speed of electro-magnetic waves agrees with that of light, *i.e.*, 300,000,000 metres per second. That is equivalent to a velocity of 12,000,000,000 in. per second, and taking the distance between the lens of the eye and the receptive organ or organs of the brain to be, say, 6 in., impulses would, according to that theory, be transmitted in $\frac{1}{2000}$ millionth of a second.

Moreover, these electro-magnetic waves would impinge directly upon the layer of optic nerve-fibres, thence upon the optic nerve-cells, and exert their electronic vibratory influence upon five other layers of the retina before reaching

the rod and cones, which we are told are the structures directly concerned with vision.

In the conversion of rays of light into waves of neuro-electricity delays which would reduce the rate of transmission to the normal velocity of nervous impulse would most certainly occur at the synapses, and quite apart from physiological research we can be reasonably sure that the impulses to which vision is due do not travel at anything like the rate at which electro-magnetic waves are propagated. Halliburton says: "The duration of the sensation produced by a luminous impression on the retina is always greater than that of the impression which produces it. However brief the luminous impression, the effect on the retina always lasts for about one-eighth of a second." That is, in perfect harmony with an electrical impulse, which, as we have seen (p. 160), always takes longer to leave the circuit than it did to enter it, but it is not in harmony with the theory that impulses are conveyed to the brain at a velocity of 300,000,000 metres instead of 120 metres per second. In the one-eighth of a second during which the retina retains the impression no fewer than 1,500,000,000 impulses would be produced by the direct vibrations of electrons, and they would continue to arrive at the same speed while vision lasted.

Some further arguments in favour of the theory I have advanced may, however, be adduced.

I have said that, in my opinion, the optic, like the auditory, nerves—and we must include their processes—are "closed" circuits. Halliburton states that the retina "possesses a store of potential energy which the stimulus serves to fire off." That is understandable in a closed, but not in an open, circuit.

"Nothing is known about the yellow pigment of the yellow spot," but a "change produced by the action of light upon the retina is the *movement of the pigment cells*."

On being stimulated by light the granules of pigment in the cells which overlie the outer part of the rod and cone layer of the retina pass down into the processes of the cells, which hang down between the rods" (see Fig. 119); "these *melanin* or *fuscin* granules are generally rod-shaped, and look almost like crystals. In addition to this, a *movement of the cones* and possibly of the rods occurs; in the light the cones shorten, and in the dark they lengthen." (Halliburton : Engelmann.)

The property of transforming rays of light into nervous impulses may reside in the "visual purple," but if the pigment cells have no part in this and are designed merely to provide the dark lining of the camera, why should they be given movement, and why do they have processes connecting, functionally if not structurally, with the rod and cone layer?

THE EAR.

The ear is divisible into three parts: *i.e.*, the external ear, the middle ear or tympanum, and the internal ear or labyrinth. Physiologically described, "the filaments of the auditory nerve end in peculiar structures buried deeply in the hard portion of the temporal bone of the skull, and special arrangements exist for conducting waves of sound to this deeply seated sensitive part. The external ear assists in collecting sonorous vibrations that pass along a channel termed the external auditory meatus, and impinge against a stretched membrane called the tympanic membrane, or drum-skin. The vibrations thus set up in the tympanic membrane are transmitted across the tympanic cavity or middle ear by a chain of small bones—the malleus or hammer, the incus or anvil, and the stapes or stirrup—to the inner ear. The membranous base of the stapes is placed in connection with the inner

ear by being fixed into an oval opening in a bony tubular labyrinth consisting of parts termed the vestibule, the semicircular canals, and the cochlea. Inside the bony labyrinth is a nearly similar labyrinth of membrane filled with liquid, a liquid also lying between the bony and the membranous labyrinth."



Fig. 123.—SCHEME OF THE ORGAN OF HEARING. (*Landois and Stirling.*)

HG, external auditory meatus; T, tympanic membrane; malleus with its head, short process (kf), and handle (m); a, incus with its short process (a) and long process—the latter is united to the stapes (s) by means of the Sylvian ossicle (z); P, middle ear; o, fenestra ovalis; r, fenestra rotunda; x, beginning of the lamina spiralis of the cochlea; pt, its scala tympani, and vt, its scala vestibuli; V, vestibule; S, saccule; U, utricle; H, semicircular canals; TE, Eustachian tube. The long arrow indicates the line of traction of the tensor tympani; the short curved one, that of the stapedius.

These liquids are known as endolymph and perilymph respectively, and according to Landois and Stirling the end-organs of the acoustic nerve lie in the endolymph and on membranous expansions of the cochlea and semicircular canals.

"The vibrations conveyed to this fluid by the movement of the base of the stapes excite the peculiar epithelium of the inner surface of the membranous labyrinth, on and in which are distributed the auditory nerve-filaments. Impulses pass from these filaments along the nerve lying in the internal meatus to the brain, and there produce that

modification of consciousness which we call the sensation of sound." (Thornton.)

Landois and Stirling say: "Normal hearing takes place through the external auditory meatus. The enormous vibrations of air first set the tympanic membrane in vibration; this moves the malleus (Fig. 123), whose long process is inserted into it; the malleus moves the *incus* (*a*), and this the stapes (*s*), which transfers the movements of its plate to the perilymph of the labyrinth."

All this, up to and including the movements of the stapes, is perfectly consistent and indeed almost identical with a telephone receiver and microphone attachment, but when it becomes a question of transfer of mechanical vibrations to nerve-filaments, or to the wires of a closed circuit, I would point out that there is no evidence that the true function of a nerve is to convey mechanical impulses. The physiological theory is that the nerve impulse is chemical. My contention is that it is neuro-electrical. It is difficult to understand how mechanical vibrations can be transformed into chemical impulses, but not at all difficult to conceive them being neuro-electrically transmitted over a closed telephone circuit.

Thornton remarks: "The whole subject of the mechanism of hearing is far from being satisfactorily settled. . . . For hearing the stimulus is of a mechanical nature." I venture to think that the utmost that can be said in favour of this hypothesis is that mechanical stimulus extends from the external meatus, by the *endolymph*, to the auditory nerve. It is the nerve, not the *endolymph*, which conveys the stimuli to the brain.

I can offer one very convincing proof that in this case at least the impulse is neuro-electrical. In purely nerve deafness the measure of nervous energy, as shown by the hand-to-hand galvanometric deflection, is not more than 30 or 40 mn.; deflections from the back of the cartilage

of the external meatus, where it adjoins the mastoid, being in accordance with that deflection, or, in other words, not exhibiting departure from Ohm's law.

In such cases, if a rod of specially prepared carbon is held by the patient for a few moments in the right hand so that the body may receive a charge of the form of energy exerted by it, the hand-to-hand deflection will rise to over 800 mm. positive, and hearing will usually return at once and remain normal during such time as the charge is retained.

Halliburton says: "The external and middle ears are conducting; the internal ear is conducting and receptive. In the external ear the vibrations travel through air; in the middle ear through solid structures—membranes and bones; and in the internal ear through fluid, first through the perilymph on the far side of the fenestra ovalis, and then the vibrations pass through the basilar membrane and membrane of Reissner, and set the endolymph of the canal of the cochlea in motion."

With great reluctance I must to some extent disagree. The external ear, in my view, is receptive, in the sense that the transmitter of a telephone is receptive of sound; the middle ear is receptive and conducting—as a microphone receives and conducts; while the inner ear transforms the vibrations transmitted, and probably amplified, by the middle ear or microphone, into neuro-electrical impulses, and conveys them in that form to the brain.

One thing, I think, can be regarded as certain. The sensory nerves, and the nerves of special sense, are "closed" circuits. That being so it follows, logically, that the quantity of endolymph or perilymph, or both, in the cochlea must not undergo diminution—that is a matter of the chemistry of the body—and that the neuro-electrical pressure, or electromotive force, present in those "closed" circuits and energising the endolymph and (or) perilymph

must be fully maintained, if normal conditions are to be preserved.

Supposing any "faults" to occur, at least three of them should be susceptible to electro-diagnosis—

- (1) The drum of the ear may be thickened or overlaid by inflamed tissue due to, say, inflammation or rheumatoid conditions.
- (2) The bones of the middle ear may be clogged by catarrh, or urates, so that they are not free to vibrate; or
- (3) The auditory nerve, or line wire, may be faulty.

In either case the vibrations do not reach the brain unimpaired, because—

- (1) They are partly or wholly stopped, or rendered "woolly" by the drum.
- (2) If responded to by the drum they fail to set fully in motion the clogged bones of the middle ear, or at all; or
- (2) The faulty line wire fails to carry them fully, or at all, to the brain.

We have, then, at least three morbid conditions to deal with, and when one of these conditions occurs the telephone system must be tested and the nature and locality of the "fault" ascertained.

If the drum of the ear is thickened, or the passage to it swollen, by rheumatoid arthritis or other causes contributory to local pyrexia, it will yield an abnormal, that is to say a high, deflection. So will the middle ear—tested by placing a suitable electrode between the mastoid and the cartilage of the external ear—if it is affected by catarrh; or it will give a subnormal deflection when the bones are, and have been for some time, clogged by urates. In much the same way the inner ear (the line wire) can be made to disclose its degree of conductivity by giving the

measure of the nerve-current in it as compared with the nerve-current present in the auditory nerve of a healthy person of similar hand-to-hand deflection. If it is partially atrophied the first step should, I think, be to restore it to its normal condition of an active closed circuit ; by, say, ionic medication.

In the case of catarrh of the middle ear, or of the presence of inspissated mucus in the middle ear, our object should be to introduce a harmless solvent into what is, practically, a closed cavity.

CHAPTER XVII

ELECTRO-DIAGNOSIS

THE GALVANOMETER AND ELECTRODES

AND HOW TO USE THEM

THE chief requirements in a galvanometer are great sensibility and perfect insulation combined with a short period of oscillation. There are several types, but in practice I prefer for research work the special form of Kelvin reflecting Astatic, made for me by Elliott Bros., although it is somewhat expensive. This instrument is designed for tests where specially good insulation of all parts of the circuit is required. There are eight coils, having a total resistance of from 60,000 to 100,000 ohms, carried in hinged frames supported by ebonite pillars; four terminals carried on tall ebonite stems through the top of the case, and a long suspension.

The medical practitioner will be quite safe, as regards sensibility, in ordering an instrument which will give a deflection of 4,000 or more mm., at a scale distance of 1 metre, per micro-ampere. The period should not be more than seven seconds.

On the next page will be found an illustration of the instrument I have mentioned.

As shown it is not adjusted. To do this it is necessary that it should be placed in the east (facing west), looking towards the scale which is from 1 metre to 41 in. distant. If it is stood upon wood the levelling screws should rest in

electro-cups, but a good plan is to let a slate or marble slab into the wall and stand the galvanometer upon it.

At the base of the instrument are two spirit-levels, and the next thing to be done is, by manipulation of the levelling screws, to see that each air-bubble lies exactly in the centre.

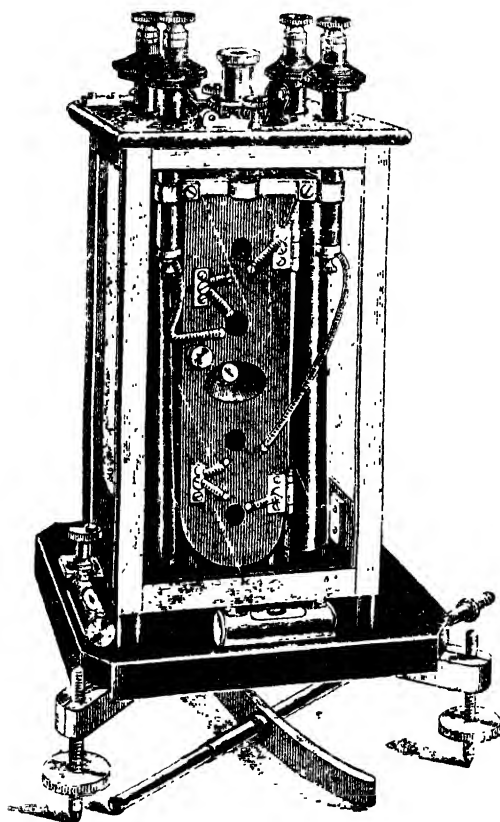


Fig. 124.

Rising from the top of the case will be seen four terminals and a central brass pillar. Unscrew the

latter. Beneath it is a pin, with a milled head (Fig. 125) to which the suspension is attached. Raise this pin, without turning, *very gently*, until the mirror is exactly in the centre of the opening and the suspension swings freely. Then replace, and adjust the controlling magnet—shown underneath the instrument in the figure given.



Fig. 125.

To do this take off the screw at the top of the rod and slide the magnet off. Then screw the rod into its seat, replace the magnet—due north and south—and the screw and the galvanometer is nearly ready for use.

Should it be necessary at any time to examine the suspension, first take off the two screws which clamp the case to the base, remove the terminals and the ebonite discs below them and the pillar, having first detached the controlling device by sliding off the magnet and unscrewing the rod. The case can now be lifted off bodily.

The next procedure is to remove the coil connection at the left-hand inner terminal, and, also on the left, there is a screw with a milled head. When this is taken out the front coils will swing to the right on their hinges and expose the suspension.

Sometimes a hair, a microscopical fragment of silk from the suspension, may connect some part of the latter with the casing and give trouble. Upon opening the coils this may be detected.

A hole, covered by a slide, at the top of the case is for the insertion of a thermometer.

As the Kelvin galvanometer is so well known, a technical description of it is unnecessary. There are several points in connection with it, however, to which attention may usefully be called.

If the instrument is placed in the east and facing west the suspension will, before the controlling magnet is in

position, come to rest in the plane of the magnetic meridian, because very small permanent magnets are affixed transversely thereto, and must, consequently, fall into line with the earth's magnetism. The purpose of the controlling magnet is to obtain a position in which it quite neutralises the earth's magnetism. To adjust zero, therefore, a rough approximation to it should be made, before the controlling magnet is in place, by turning the milled suspension pin to the right or left as the case may be—but avoiding anything approaching a complete turn—then putting on the controlling magnet and moving it gently out of the north and south until the reflected spot of light nears the zero of the scale. Further and more delicate adjustments may be made by turning the screw at the back of the pillar, and that operating the ratchet upon the scale-stand.

Sensibility may be varied by, also *very gently*, moving the controlling magnet up or down its support.

Advantage may be taken of the equal number of coils to make the instrument differential. That is to say, by using the two sets of coils separately one current may be sent in one direction and another current in the opposite direction, so that comparison may be made of their respective strengths. If both are exactly equal there will be no deflection, but if one is stronger than the other the spot of light will travel over the scale and indicate the excess. By preliminary experiment the direction of deflection by each current can be determined separately, and in this way the difference of intensity between the two ascertained.

In experienced hands this galvanometer is as near perfection as anything made by man can be, but, unlike those of the moving-coil type, it is directly affected by any outside vehicle of magnetic or electrical energy. The near proximity of a steel key or even a steel trousers' button is sufficient to cause a movement of the light, and so sensitive is it to induction that it cannot be used

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satisfactorily within three-quarters of a mile of an electric railway or tube or charging station by reason of the frequent alteration of load. It is true that, as the human body is similarly affected, the argument must also apply to any galvanometer, but in research work one is not always testing the human body, or dealing with such infinitesimal electromotive forces and currents.

The cost price of this form of Kelvin is about £30.

We will now consider an instrument of the d'Arsonval type, which, with equal sensibility, can be bought for about £10.

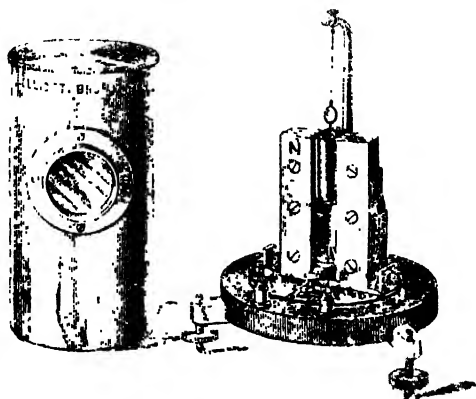


Fig. 126.

In this the reflecting mirror does not carry a magnet, but is directly connected with the coil, which, as will be seen, is suspended between the poles of two laminated bar-magnets. At the suspension-head there is a milled pin, by means of which the suspension may be raised or lowered, and a movable head which may be turned one way or the other to adjust the zero. No spirit-levels are provided, but the instrument may be levelled by placing a small spirit-level upon the base—as shown in the other instrument—and testing it by means of the levelling screws, taking care that the coil swings freely and is equi-distant between the

poles of the magnets. The cover is then replaced and clamped on with the screw provided for the purpose.

THE SCALE.

It is clear that a light must be thrown upon the mirror of the galvanometer and reflected back upon the scale. There are two ways of doing this. One is to have the direct light at the back of the scale, thus—

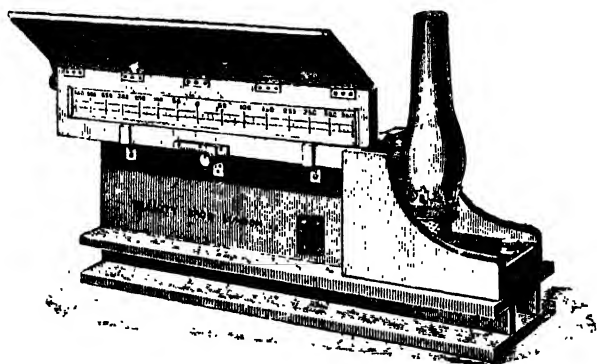


Fig. 127.

This is a cheap pattern of scale, but is quite useful for all purposes where the observer can place himself close to it. In testing the human body, however, the positions of the galvanometer, the scale, and the patient in relation to the observer have to be considered, and it will be evident that with the patient several feet away from the scale the observer must be at some disadvantage. To obviate this difficulty it is better to have a transparent scale (Fig. 128).

It has a mirror upon a universal joint. The lamp faces the same way as the galvanometer. Its light is thrown upon the scale, reflected therefrom upon the mirror of the galvanometer, and thence back to the scale. The height of the scale is adjustable, and there is a ratchet arrangement to move the scale itself some inches to get a true zero.

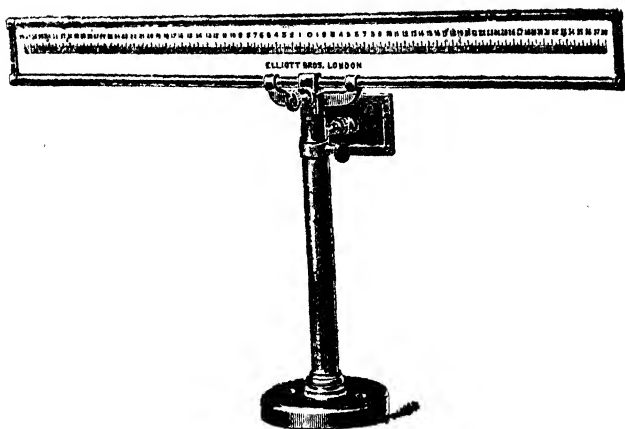


Fig. 128

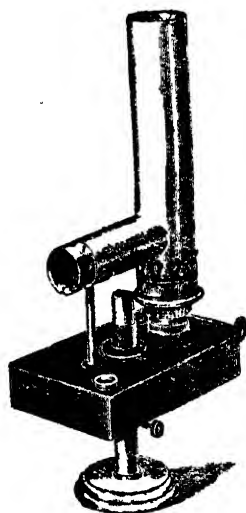


Fig. 129.

In this way, almost irrespective of the position of the patient, the operator can be within easy reading distance of the scale.

THE LAMP.

The temptation to have an electric lamp, preferably affixed to the scale-stand, is great. It offers the advantages of a brighter spot and less halation, but there is always the danger of leakage, and for this reason I recommend a paraffin lamp. A useful type is Fig. 129. There is a lens, across which there is a vertical wire so that the spot of light upon the scale appears as in Fig. 130; but it is better, in avoidance of halation, to paint the lens with dead-black, leaving only a vertical line $\frac{1}{2}$ in. wide in the centre. The spot then appears as in Fig. 131, and can be more conveniently and accurately read.

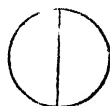


Fig. 130.

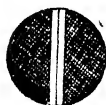


Fig. 131.

THE SHORT-CIRCUIT KEY.

Fig. 132 shows a very useful and reliable form of short-circuit key, but I have found a cheaper pattern answer quite satisfactorily upon substituting a brass bar for the ebonite one shown in the front of Fig. 133.

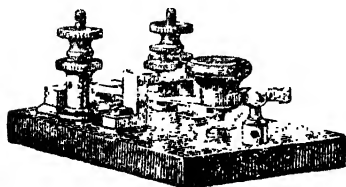


Fig. 132.

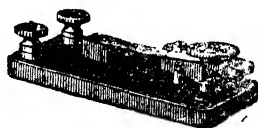


Fig. 133.

SHUNTS.

For research work a shunt in terms of the galvanometer, and proportions of $\frac{1}{9}$, $\frac{1}{99}$, and $\frac{1}{999}$, is desirable for use in conjunction with the high-resistance instrument.

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For electro-diagnosis, however, a shunt is unnecessary, and as the resistance of the coil of a d'Arsonval galvanometer seldom exceeds 2,000 ohms, it should not be used with that type of recording instrument at all. If, however, it is desired to do so, a "universal" shunt is recommended.

It is a golden rule to "limit the apparatus." To avoid leakage is to avoid trouble. Let the top of the testing-table be of teak or other hard wood, and paraffin-wax it. Also have a gas-fire or electric radiator in the testing-room and maintain a standard temperature.

CONNECTING WIRES.

To connect the galvanometer with the short-circuit key and electrodes use the best electric light flex (30 to 40), untwisting same so as to have single wires.

EARTH CONNECTION.

Thick (preferably insulated) copper wire soldered to the water-main and the other end brought and connected to a copper rod or tube in the testing-room, makes a very good "earth."

THE ELECTRODES.

These are seven in number, and are made for me by Messrs. Hodges & Co., of St. John Street, Clerkenwell. For the hand-to-hand deflection I use solid German silver

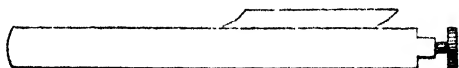


Fig. 184.

rods (heavily silver-plated), $5\frac{1}{4}$ in. by $\frac{3}{4}$ in., provided with a thumb-piece and a terminal at the upper end (Fig. 184), the thumb-pieces being shaped as Fig. 185 in plan.

German silver has a low co-efficient of increase of resistance with temperature, and, when heavily plated, is a very suitable alloy.



Fig. 185.

When one of these electrodes is held in each hand by the patient the thumbs are pushed up to the closed ends of the thumb-pieces, the fingers used merely in support and no pressure exercised. The connections are then—

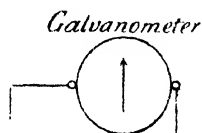


Fig. 186.

Short-circuit key omitted.

The other electrodes consist of an elastic rubber band, to encircle the head, carrying a circular plate of silver (or German silver heavily plated) 1 in. in diameter and provided with a terminal of the same metal :—

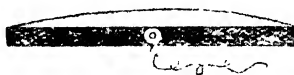


Fig. 187.

For purposes of electro-diagnosis this is connected by a wire to one terminal of the galvanometer, and the band fitted round the head of the patient in such manner that the flat

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surface of the circular plate makes contact with the centre of the forehead ; the circuit being completed by means of another electrode—



Fig. 188.

These, preferably, should be three in number ; the boss, *a*, having diameters of $\frac{1}{2}$ in., $\frac{3}{16}$ in. and $\frac{1}{16}$ in. respectively.

The readings obtained, as I explain later on, will be in conformity with the hand-to-hand deflection and Ohm's law.

In the galvanometric diagnosis of morbid conditions the *sign* of current is of little importance. All the deflections are comparative. The one thing that matters is the *quantity* of current issuing from any part of the body, and this is shown by the relative *rapidity* of the excursion of the light upon the scale ; the gradations being from a very rapid off-scale deflection in the case of acute local pyrexia to no deflection at all in cancer.

For diagnosis I recommend the use of a large head plate, for the reason that it is imperatively necessary to cover the central line in order to obtain accurate comparison between two symmetrical parts of the body, but in research work, as, for instance, attempting to differentiate efferent from afferent nerves, *sign* of current is of the utmost consequence, and the head-plate must, therefore, be of exactly the same area and resistance as the electrode used to complete the circuit.

Formerly I had all these electrodes made of solid silver, but it involved a quite unnecessary expense.

CHAPTER XVIII

OHM'S LAW

IN ITS APPLICATION TO THE HUMAN BODY

As I have frequently mentioned Ohm's law, and have said that all body deflections must conform to it, I will, for the guidance of the medical practitioner, explain it so far as may be necessary. I have given it, briefly, as $C = \frac{E}{R}$; that is, the current at any point is equal to the electromotive force divided by the resistances in circuit at that point, assuming both electromotive force and resistances to be constant. But that is only a part of Ohm's law, and we must ponder it further to see whether it in any way conflicts, or in every way agrees, with observed phenomena.

As most of my readers will be aware, the unit of electromotive force is called a *volt*, that of resistance an *ohm*, and that of current an *ampere*. The quantity of electricity which flows per second in a current of one ampere is known as a *coulomb*, and the capacity of a condenser in which a charge of one coulomb causes a potential of one volt is said to be a *Farad*.

To put it in terms of hydrostatics, with which everyone will be familiar, E is the head of water (pressure); R is the resistance offered to flow by the inner perimeter of the pipe (in the inverse ratio to the sectional area of the pipe); C represents the quantity of water flowing through the pipe at any point, and is, obviously, $\frac{E}{R}$; while the coulomb may be said to be the unit of effective discharge.

Furthermore, the Farad is a unit—as, for instance, a gallon—of the capacity of a cistern into which the water may be caused to flow from E, and in which the quantity of one coulomb produces a pressure of one volt, by creating, as it were, another head of water at a lower level.

For a circuit to be established it is necessary in the case of electricity for there to be a return, either by another wire or by the earth; there must be a “loop.” Similarly no water will flow from the cistern unless it has access to air, nor will any water issue from a pipe unless and until the tap is opened to air.

The resistance of a metallic conductor is directly proportionate to its length, is in the inverse ratio to its sectional area, and is expressed by R . There are, however, resistances (r) other than that of the conductor or conductors to be taken into account, and the principal of these (outside the galvanometer and electrodes) is the internal resistance of the generating cell or cells. This varies not only with the surface area of the plates but in a galvanic cell with the chemical composition of the exciting fluid.

Briefly summed up, the E.M.F. is proportional to the current when the resistance is constant, the E.M.F. is proportional to the resistance when the current is constant, and the E.M.F. is proportional to the product of current strength and resistance when both vary.

The resistance of metals *increases* with rise of temperature, while that of liquids and dielectrics *decreases* more or less rapidly.

When there are two conductors of different resistance joining two points, the current in either branch is inversely as the resistance of that branch.

In reviewing the galvanometric deflections exhibited in normal health by the human body we must bear in mind certain facts of primary importance. The conductors (nerves) and condensers (certain cells) are composed of

moist substances, and their conductivity, instead of their resistance, increases in a physiologically defined ratio with rise of temperature, while the electromotive force fluctuates during certain periods of the twenty-four hours and also in accordance with the degree of fatigue to which the patient has been subjected. It will be seen, therefore, that while R may be constant, neither E nor C can be said to be so. For this, if for no other reason, the hand-to-hand deflection must be carefully taken. When this is done all the body deflections must, by Ohm's law, be in conformity with it.

Another point which calls for consideration is the *capacity* of our condenser-ganglion cells and condenser-compartment muscular fibres. We have seen that a capacity of one Farad with a quantity of one coulomb causes a potential of one volt, and the fact that we have to go into minute fractions of each unit does not affect the law.

The potential at any point (supposing R to be constant) is liable to variation by any difference in E (producing a difference in C), while a rise or fall of temperature may not only alter the resistance of R , generally or locally, but also the internal resistance (r) of all or some of the cells.

Care, then, must be taken when galvanometric examinations are made to observe the temperature of different parts of the body, as one part may be colder than another, and by giving a subnormal deflection introduce error into diagnosis. Furthermore, the utmost vigilance must be observed to ensure the conditions of contact being equal, as, if one part of the skin is more moist than another, the result, generally speaking, will be a higher deflection from that part. Inversely the presence of fat in the skin and subcutaneous tissue would tend to interpose resistance and therefore diminish the deflection, etc.

We may now proceed with our illustration. When any amount of resistance is introduced between the

The potential gradient gives us potential *differences*, and not the absolute potential at any point. If the cell and circuit be all insulated, the potential at some parts will be + and at the other parts —, depending upon the *capacity* of the various parts of the circuit. If we connect the circuit with earth at any one point, we have only to draw a line parallel to the base line through the corresponding point on the gradient, and perpendiculars to this line will then give the absolute potential, positive when above and negative when below this line. The figures drawn would represent the potential, supposing the zinc plate to be to earth. (Cummings.)

It is, of course, a matter of extreme difficulty to apply Ohm's law to the human body in the absence of more definite information as to its electrical structure and in view of the changes which occur, even in normal conditions, in its E.M.F., capacity, and resistances; but I am convinced that when the nervous system is studied on electrical as well as chemical lines and in relation to this law, a great advance will be made in our knowledge of the human organism.

HAND-TO-HAND DEFLECTION.

In taking the hand-to-hand deflection several precautions are necessary—

(1) The patient should be placed in contact with an "earth" of low resistance for five or, preferably, more, minutes before testing. A copper rod or tube connected by an insulated wire (with a *thick* conductor) to the water-main makes a very good "earth."

(2) Rings must be removed from the fingers, as they introduce difference of contact; and all steel, such as keys and knives, from the pockets, as steel is always more or less magnetic. Gold, silver, and copper coins do not matter.

(3) The hands, after " earthing," must be washed with soap and water, and not only dried with a towel but given an interval of at least five minutes before testing.

(4) During the time that the subsequent testing of the body takes place it is desirable that the number of persons in the testing-room should be limited to the patient and the observer. But this is not always possible. In certain cases a medical attendant and a female friend or a nurse must be present, but in these cases such persons should be stationed as far from the patient as possible, and not admitted to the testing-room until the hand-to-hand deflection, both as regards sign and quantity, has been accurately determined.

APPLICATION OF OHM'S LAW TO SOLUTIONS.

Where $E = \text{E.M.F.}$, and l is the distance between electrodes.

Generally speaking, " the velocity of the ions is proportional to the value of the motive force $\frac{E}{l}$."

Such a law as that " the velocity with which a particle moves under the influence of a certain force is proportional to this force " is valid for all liquid or gaseous particles moving between other liquid or gaseous particles so long as collisions constantly take place. This law can be derived from the principles of the kinetic theory of gases, as is proved in treatises on internal friction.

" We must imagine the ions as particles of a liquid which receive an acceleration under the influence of some external force, electrical or osmotic, and the velocity imparted is proportional to the force acting. The ions, like liquid particles in general, become more mobile as the temperature rises." (Arrhenius.)

CHAPTER XIX

THE INTERPRETATION OF CERTAIN
ELECTRO-PHYSIOLOGICAL PHENOMENA

THERE are in the human body many structures and substances which, although not in themselves of very high resistance, may, in view of the low tension of the nerve-current, be termed dielectrics. Among these are the sheaths of medullated and the lipoid coatings of non-medullated nerves; the capsules and membranous coverings of and in cells; the sarcolemma and neurilemma; Krause's membranes of voluntary muscular tissue, neuroglia processes and connective tissue, etc.

The effect of heat upon any and every known dielectric is to lower its resistance.

To ascertain, for instance, the relative resistance of gutta-percha at different temperatures we have the formula—

$$\text{Log } R = \log r - t \log 0.9399$$

where R = resistance at higher temperature,

r = resistance at lower temperature, and

t = difference in temperature in degrees F.

Reduced to figures, the relative resistances, calculated from the curve, are: 75° F. = 1.000; 90° F. = 0.407; 100° F. = 0.223; 110° F. = 0.137.

In acute inflammation the *local* temperature—that is, the temperature in the area affected—may rise at least ten degrees F. above normal; and this would, for gutta-percha, give us 0.4068 (at 90° F.) and 0.2233 (at 100° F.),

or a fall of nearly fifty per cent. of resistance, or (roughly) five per cent. per degree.

Inasmuch as the human nerve-current escapes through the dielectrics of the body, despite the fact that the tension is not more than from 4 to 5 millivolts, it is evident that their resistance is infinitely lower than that of gutta-percha.

We have no means of determining with accuracy the resistance of any of these dielectric structures or substances in their natural and normal environment, nor, while we know that a rise of temperature affects them adversely, must we at once assume that the relative fall in resistance of a nerve-sheath is the same as that of gutta-percha. Maxwell's recent experiments, however, went to show that a rise of 10° C. approximately doubled the velocity of nerve-conduction by lowering the resistance of the nerve-substance.

Heat decreases the resistance of liquid and increases the resistance of metallic conductors in a known ratio. Comparing a nerve with a copper wire, the increase in resistance of copper per 10° F. would be one-fifth or twenty per cent. = to two per cent. per degree, but the fall in resistance of gutta-percha due to the same increase is nearly fifty per cent. By this process of reasoning we find some ground for the belief that the effect of temperature upon the dielectrics of the body is approximately the same as upon gutta-percha; involving roughly a fall of five per cent. per degree Fahrenheit within certain limits, although I believe the loss to be much greater.

Now, it is quite obvious that if the organs of the body connected with the transmission of impulses, the maintenance of neuro-electrical equilibrium, the conservation of energy, and the contraction of muscular tissue are to function properly, the temperature of every part of the whole organism must not exceed the normal, which we may

take it to be, subcutaneously, about 100° F. Protoplasm dies, I am informed, at about 114° F., and as we know that cells *do* die in the area affected by acute inflammation, we have a right to postulate that, in that area, there may be a rise of temperature of at least 10° F. above the normal.

And with what result?

Suppose a submarine telegraph cable to connect two stations, A and B, and the battery at the sending station, A, to have just sufficient E.M.F. to overcome the resistance and allow for the leakage of the cable and actuate the receiving instrument at B. What would happen if at some point intermediate between A and B the dielectric—the gutta-percha—of the cable became heated to 110° F.? There would be a loss of fifty per cent. of its insulation, an escape to earth at the fault and interrupted or faulty communication with B. The following diagrams will make this clear, assuming the leak to be equidistant between A and B—

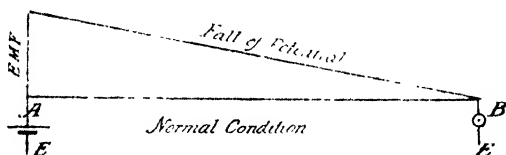


Fig. 141.

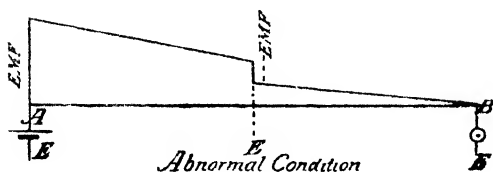


Fig. 142.

That, approximately, is what occurs when the resistance of, say, a nerve-sheath, or the coating of a non-medullated nerve, is partly broken down by the rise of temperature

incidental to inflammation, and as a consequence the nervous impulse or current is not conveyed at normal pressure to its destination, to supply blood-vessels, to actuate muscular fibres, or to energise or transmit messages to various cell-groups.

Nor is this the full extent of the mischief. The current escaping through the fault, in conformity with natural laws, seeks the path of least resistance to earth (air), and from that point throughout that path the cells are in a highly electrified area, and, their insulation not being capable of withstanding the strain, they in all probability become over-ionised. A condition is thus created favourable to the multiplication of inimical bacteria and unfavourable to phagocytosis.

The path of least resistance must be from the fault through the intervening tissues and the skin, to air, and generally, it will be the shortest path. But wherever it is it is clear that an abnormal quantity of current must issue from that part of the skin in which the "path" terminates, and that if we place the circular plate upon the centre of the forehead of the patient in order to be sure of getting on the central line, and another electrode upon the affected area—both electrodes being, of course, connected to the galvanometer—the fault will manifest itself by a more or less *rapid* excursion of the light upon the scale; that is to say, the rapidity of the excursion will be proportionate to the *quantity* of neuro-electricity escaping, and that quantity will also be proportionate to the rise of local temperature or to the degree in which local insulation resistance has been broken down by temperature.

Let us, for example, take a case of lobar pneumonia, the base of the right lung being affected (Fig. 148).

Here, after taking the hand-to-hand deflection, we are able to make intelligent comparison of the galvanometric readings from the affected and the unaffected lung, or at

all even, from two symmetrical parts of the chest and back. Whatever the hand reaction was the body deflections would all be lower, because of the resistance interposed not

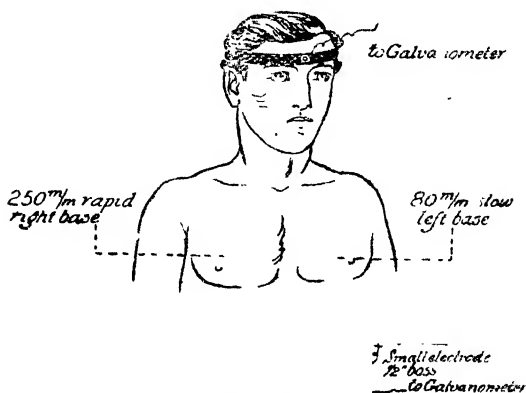


Fig. 143.

only by nerve-substance but by sebaceous glands and fat cells, and in no case would the light, under normal conditions, exhibit a *rapid* movement upon the scale. In the above illustration we have obtained deflections of 80 mm. *slow* upon the unaffected, and 250 mm. *rapid* upon the affected side, and have found the rate of travel increase as the electrode touched the skin on the *centre* of the spot of "least resistance." That would, with a galvanometer of the sensibility I have described, postulate semi-acute inflammation and indicate a fairly high local temperature, but in a very acute case the light would be seen to fly off the scale.

In double pneumonia there would be a short-circuit between the two lungs, or the affected parts of them, and the path of least resistance, common to both lungs, might be from the left lung or the right, to the skin.

These remarks apply to galvanometric observation of all forms of local pyrexia. As regards the exact internal position of the fault, the deflections should, theoretically,

be the same from the back and front when the "fault" is equidistant, higher from the front when it is nearer to the front, and higher at the back when it is nearer to the back, but in practice the conditions of contact must be studied and allowance made for them. As a rule, the skin of the back is more oily or greasy than that of the chest. A little experience, however, will enable the physician to make correct diagnosis.

In order to make clear much of that which in physiology remains obscure it is only necessary to reason in terms of highest potential of nerve-force in the brain and differences of potential in the body, or, to put it another way, in terms of hydrostatics; the brain being the constantly maintained head of water, the nerves—the motor and secretory paths—the pipes through which it flows, and differences of potential being differences of level.

The sensory nerves may be compared with pipes filled with water at an adjusted pressure, and the impulses conveyed by them to the brain to the undulations or vibrations transmitted through them by reason of any disturbance of that adjustment.

Thinking along those lines, we may more intelligently conceive how and why it is that local pyrexia manifests itself, electro-pathologically, as an expression of greater quantity of nerve-current in the part affected. *It is an expression of lower level*, because the resistance of the path is lowered. Normally the resistance, if we consider it as level, would be represented by the line *ab* in the following diagram :—

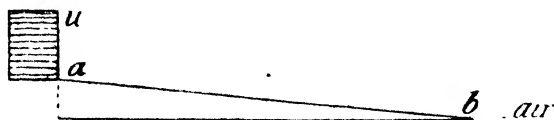


Fig. 148A.

The head of water—the vertical line *au*—remains unaltered

throughout, but owing to local pyrexia at *b* the level is altered and the diagonal may become—



Fig. 143b.

giving the effect of increased pressure and consequent greater flow.

Not only is this so, but as a local rise of temperature lowers the level of issue, it, at the same time, enlarges the diameter of the pipe, in the area affected, by increasing the conductivity of the moist conductor, the nerve-substance; so that we have not only a lower level, but what may be likened to an artificial head of water created in the path *a, b*.

Similarly alterations of resistance in the form of *added* resistance due to disease may be thought out. Between acute local pyrexia, such as lobar pneumonia with a body temperature of 106° F.—involving, possibly, a local temperature of 116° F.—and cancer, there would be the widest margin, because the cancer cells are devoid of conductivity. In the latter case our diagram might become—



Fig. 143c.

and there would not be any flow at all from *a* to *b*.

There are many gradations between the two extremes, but after due allowance has been made for skin conditions,

sebaceous glands, and so forth, it will be found that differences of resistance imply differences of level, and that those differences, as shown by the galvanometer, may, with care, guide the way to correct diagnosis.

Some physiologists have endeavoured to explain wide deflectional differences as being due to varying conditions of contact, that is to say, to the presence of more or less moisture in the skin. But in pyrexia, local or otherwise, moisture is conspicuous rather by its absence than its presence, and it will be found that a hot, dry skin will, when it is associated with inflammation, always give a higher deflection than is obtainable from any part of the body not so affected.

In febrile diseases it is generally the first care of the physician to get the skin to act.

Moreover, experience has shown that in a number of cases of nervous asthenia the hand-to-hand deflections, despite the fact that the palms were wet, were all low (40 or 50 mm.) and all negative, reverting only to the positive side of the scale upon convalescence.

IMPAIRED CONDUCTIVITY.

A converse condition is when there is a partial failure of inter-cellular conduction, due either to increased resistance of the nerve-substance or to some change in the ionic cell contents by which they are rendered less active. It very frequently happens that a painful disorder is diagnosed as neuritis or sciatica and that treatment gives no relief. True neuritis, as I understand it, is an inflammatory condition, caused by the insulation resistance of a sheath of nerve or nerves being interfered with by local pyrexia. In my experience the neuritis we hear so much about is sometimes not so. It is, perhaps, in five cases out of ten, due to some toxin. Pyorrhœa, the internal administration of nux vomica, post-diphtheritic poisoning, inoculation by

cert. in sera, and chill are direct causes, and in every case the affected part will yield a subnormal deflection, indicating treatment by ionic medication.

VARIOUS FAULTS.

When there is any functional throat trouble, asthma, or irregular action of the heart, the vagus nerves should always be tested by placing a small electrode ($\frac{1}{2}$ in. boss) directly below and a little forward of the angles of the jaw; while "nervous breakdowns," excessive nervousness, insomnia, and some uncertainty of movement may have their origin in spinal faults which can be readily detected.

I remember one case of supposed epilepsy (*grand-mal*) in the patient of a medical friend. The pulse was 40, the eyes lack-lustre, and fits (so-called) were of frequent occurrence. Galvanometric examination revealed a line of chronic inflammation extending from the base of the cerebellum to the right cervical. Under dielectric treatment the pulse went from 40 to 70 in a fortnight, his health became normal, and he has since been able to pursue his avocations. His trouble was that when the inflammation became acute—as it did from time to time—and the quantity of nerve-current escaping became excessive, he fainted.

I mention this merely to emphasise the importance of the galvanometer in obscure morbid pathology.

Reverting for a moment to the vagi, it must be borne in mind that they have both efferent and afferent branches, and that when they or one of them exhibit a high and *intermittent*—both positive and negative—deflection, it inferentially argues intermittent contact between those branches. The afferent branch is sensory but the efferent is not; the escape, therefore, from the sensory branch might be constant and that from the efferent only active when the nerve conveyed an impulse.

ON DISEASE IN GENERAL.

In connection with electro-diagnosis I have postulated, both verbally and in print, that any physical change in the body must be attended by a neuro-electrical change, which can only be galvanometrically detected; and that the process of restoring the one to normality tends, automatically, in the great majority of disorders, to restore the other to normality.

Disease is a deviation from the state of health, implying some alteration in the functions, properties, or structure of some organ or tissue, and may be generally described as an abnormal performance of the processes constituting life. That being so, it would be illogical to imagine that one of the most delicate and most necessary of those processes, *i.e.*, the maintenance and regulation of the neuro-electrical system, could proceed without deviation in any diseased area.

GALVANOMETRIC TESTS OF OTHER DISEASES.

NEURASTHENIA.

To my mind a knowledge of the electro-pathology of this disease is of vital importance to humanity, as, so far, it is imperfectly understood and, therefore, imperfectly dealt with. Neurasthenia, of course, means nervous weakness, but viewed from an electro-pathological standpoint it has a characteristic which differentiates it from any other irregularity of the nervous system with which I am acquainted, and which I believe to be peculiar to a new disease. It certainly has one feature in common with nervous weakness, and that is a deficiency of nerve-energy; but while asthenia exhibits a low hand-to-hand deflection, it is constant, whereas the neurasthenic deflection is so variable as to sign of current that the light is never at rest. It may be anything from 5 to 90 mm. or so, but will be both positive and negative, moving slowly and erratically backwards and forwards, from one side of

zero to the other, never becoming constant or giving any definite indication of the normal electrical *sign* of the patient. This irregularity, this fluctuation, combined with an insufficiency of nerve energy, is a peculiarity of neurasthenia, distinguishing it from other nervous affections.

The behaviour of the sufferer from this disorder is, as a rule, consistent with the galvanometric reading. There is a corresponding fluctuation of will. Victims to neurasthenia are slow to admit to others that there is anything wrong with them, and if treated will not long submit to the same treatment, but go from doctor to doctor, or try a few doses of every quack medicine they see. They never seem to know their own minds for many minutes together, and in this respect their mental and neuro-electrical symptoms appear to be in accord. They may, reasonably, be termed neurotic, but this is perhaps a misnomer. The fault, theoretically, can be said to be partly due to intermittent contact between efferent and afferent centres and consequent disturbance of neuro-electrical equilibrium, involving defective distribution of nerve-energy.

EPILEPSY.

It follows, as a matter of course, that anyone engaged in electro-pathological research would bestow a maximum of attention upon this awful scourge of humanity, and I have been fortunate enough to have had many opportunities of studying it. My observations, however, are strictly confined to the neuro-electrical problem presented by the disorder, and even from this comparatively narrow point of view it exhibits so many complex features that I am quite at a loss for a well-grounded opinion of its origin, or of the predisposing cause or causes. I know what happens, but how or why it happens is hidden from me, though it will certainly be revealed to some other student. In this connection it is my earnest hope that such data as I am able to offer may prove to be of value.

The principal neuro-electrical phenomena common to grand-mal are low body deflections, combined with sub-normal body temperature, excessively high head deflections and temperature, and a point of least resistance at some part of the skull, from which, during an aura or during and directly after a fit, an abnormally high deflection is obtained.

The direct cause of the fit is, in fact, a species of neuro-electrical brain-storm, and this storm is unquestionably due to the nerve-force supplied to the brain not being able to find its proper outlets or channels from the brain to the nervous system—the afferent nerves, conductive from without but not receptive from within, possibly adding to the pressure—with the inevitable consequence that the pressure in the brain becomes unbearable, and produces a fit. Were this pressure not relieved, death or insanity would probably ensue, but Nature provides for this contingency by creating in the skull a path of least resistance to the passage of the pent-up current to air. The exact spot must be tested for and located in each case, and it is from this spot—a safety-valve—that the highest head deflection is obtained.

Too much importance can hardly be attached to the existence of this “safety-valve,” because it not only points to a means of alleviation, but affords convincing proof of the soundness of the theory I have advanced.

If the hair covering the “safety-valve” is shaved off and a small silver plate is fastened upon it (the valve) by means, say, of adhesive plaster, and an elastic belt carrying a circular metallic plate, provided with a terminal, is placed round the waist in such manner that the body-plate makes contact with the skin, preferably 2 in. above the navel, it is only necessary to connect the two plates by a wire—a shunt-circuit—to bring in a few minutes the head and body deflections and temperatures to normal.

There is at least one other proof. If the patient is watched and an aura detected, no fit will ensue if the head is at once wetted with warm salt water, to lower the resistance of the scalp and create an artificial path to air for the congested nerve-force.

Whatever the cure may eventually prove to be, it must, as one of the curative measures, have the effect of preventing the brain from becoming neuro-electrically congested and the body neuro-electrically starved. It has only recently been suggested to me by Dr. E. W. Martin, and I have had no opportunity of putting the hypothesis to the test, that a careful galvanometric examination of the spinal cord may disclose such high resistance in some anterior part of it as to suggest a temporary break of continuity. If that feature is exhibited in a number of cases it will be worth while to try to remedy the condition—i.e., restore conductivity—by local ionic medication. That is a matter for further research and experiment. In the meantime no one suspected of a tendency to epilepsy should be permitted the use of hair pomades or oils, or, above all, of peroxide of hydrogen.

As a final word upon this subject I should like to express my opinion of the therapeutic value of the bromides of potassium and ammonium. They act by checking the generation of nerve-force in much the same way that they act in photography. They check development—and especially mental development—and between a choice of two evils I do not know which is to be preferred; bromide saves trouble to others, at the expense of the patient.

CANCER.

Notwithstanding the fact that many hundreds of the most notable men of their day have devoted and are devoting their lives to the study of cancer, it is unfortunately true that the *fons et origo* of the disease still remain

in obscurity. Cancer has yielded nothing to bacteriological research. Surgery cannot claim that the knife is an infallible cure, because the surgeon can never be sure that he has removed the entire growth; electro-cautery has proved to be merely useful, and medicine has not been able to provide more than temporary relief from pain. From galvanometric research also nothing *decisive* has been learned, but I am encouraged to think that this is because the opportunities of observation and study have been too few in number, and that the little we have gained will at all events stimulate other workers to renewed investigation upon the lines I have ventured to lay down.

Of cases of suspected cancer I have tested many, but of cancer certified to by high medical authority not more than half a dozen. This, it may be thought, does not warrant me in coming to any definite conclusion as to the electropathology of this disease, but if I disagree it is because in all those six cases not only did I find the cancer cells to be non-conducting, but my observations have been borne out by others.

From a cancerous growth, more especially if it is not deep-seated, no deflection whatever will be obtained, even if the skin be moistened, although the secondary deposits may exhibit lines of acute inflammation. The only means of alleviation or cure suggested by galvanometric research do not, so far, go beyond restoring conductivity to the deionised cells by suitable ionic medication, but the galvanometer should provide valuable assistance to the operating surgeon by enabling an accurate diagram of the *whole* of the affected area to be drawn upon the skin. The disease, as we know, frequently recurs because complete excision has not been made.

APPENDIX

ELECTRICAL CONDITIONS OF THE EARTH

IN the first section of this work I have said that in countries free from magnetic and seismic disturbances and in ordinary conditions of weather the earth is the negative terminal of Nature's electrical system. That is a statement of fact, but modernity has, in some of the large towns of the world, introduced a new factor in a multiplicity of electrical railways and "tubes," and this factor must be considered in relation to the accepted theory that, as compared with all other electrical tensions, the earth is regarded as zero.

In body-testing it is necessary that it should be, approximately, so. There must always be a transfer from a plus to a minus quantity when there is direct conduction. If the transfer is made inductively then the problem becomes one of tension and spark-gap.

In electro-diagnosis and body-testing generally the patient must be connected for some minutes with an "earth" of low resistance in order to remove any possibility of charge from a source of energy other than that of the body itself, and if this is to be accomplished it follows that the tension of the body must be plus and that of the earth minus, otherwise there would be a transfer of electricity from the earth to the body instead of from the body to the earth.

In certain localities, and in abnormal conditions of weather in other localities, the earth may become very highly charged, and unless this is taken into account results may be obtained in testing which will perplex the observer.

In order to illustrate my meaning we may usefully ponder earth conditions during a thunderstorm, in relation to contour and nature and conductivity of soil.

Let us disregard for the moment the terms positive and negative and substitute for them the words "plus" and "minus."

The air, the upper stratum and, hypothetically, stretching upwards to infinity, is always "plus"; the earth, normally, "minus."

Between the charged cloud and the comparatively uncharged earth there is an air-space—the spark-gap—and unless the tension of the cloud is sufficiently high to bridge it no discharge can take place. Suppose the surface of the earth to be flat—

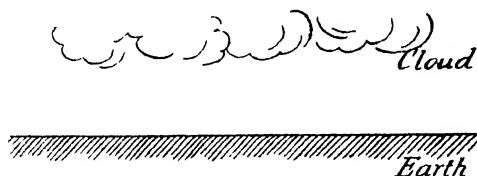


Fig. 144.

or, alternatively, the surface to be very dry or composed of some more or less dielectric material. The cloud would—unless the tension were extraordinarily high—travel over



Fig. 145.

such ground without discharging. When, however, by reason of contour, the distance between earth and cloud was lessened to one that the tension of the cloud could

overcome, or, alternatively, tension being sufficient, a point was reached where the soil favoured conduction, a transfer of potential from the plus cloud to the minus earth would at once take place, in exactly the same manner that a spark is obtained from a Leyden jar or induction coil when the conducting knobs or points are approached near enough to each other. Scientifically this is termed a disruptive discharge. It occurs when the air becomes strongly strained by the potential difference, and, suddenly yielding, allows the discharge to pass, not freely as through a conductor, but by a violent disturbance of the molecules of air along the path, which become strongly heated, and make the visible spark. This takes a zigzag and forked path which in all probability is the line of least resistance, and is due to irregular distribution of conducting motes in the air, or to its hygrometrical condition.

However this may be, we will imagine that at the point A (Fig. 146) the sub-soil is of such a nature that the charge which it has just received from the cloud cannot be readily dissipated, and that another cloud which has discharged itself in the immediate vicinity passes over it within a distance over which the spark-gap can be bridged. The

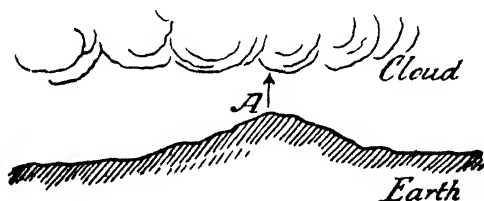


Fig. 146.

result must be that discharge will take place from earth to cloud, because the cloud is the minus and the earth the plus quantity ; but it does not necessarily follow that such discharge must be from the exact area which first received

it ; it is only required that the plus and minus quantities should be earth and cloud respectively.

In the same way the human body is liable to be influenced not only by being placed in an earth circuit but by induction ; its normal electromotive force of four or five millivolts can only be a plus quantity in favourable circumstances.

In reviewing the electrical phenomena consequent upon the operation of such a system as the District Railway, we may read for electrified clouds the effect upon the air of alterations of load, while the iron-clad tubes with their far from perfect insulation must be responsible for artificial earth-currents of such potential as to seriously interfere, over a very considerable area, with electro-diagnosis.

Similarly in tramway lines where direct current is employed the overhead system is likely to affect the air locally, and the conduit system to charge the earth, although the range of inductive interference is not nearly so great as in the case of railways and tubes.

Quite apart from these artificial disturbances, the hypothesis that in an electrical sense the earth is zero should not be too readily accepted. Prior to important experiment an " earth " should be tested galvanometrically, and although in certain localities the test may be dispensed with in ordinary work, it is a precaution to be recommended.

As a matter of fact the earth is electrically " patchy," the potential and direction of current varying greatly in different parts of the world. Darwin found the neighbourhood of the Rio Plata to be peculiarly subject to electrical phenomena and was inclined to suspect that thunderstorms were very common near the mouths of great rivers.* On the East African coast the earth-current has remained at about forty volts for many weeks in succession. At that

* *Journal of Researches.*

tin. I was stationed at Delagoa Bay, where the English, Temb , Umvelosi, and other rivers debouch. Thunderstorms during the rainy season were of very frequent occurrence. Durban, some 360 miles south, is situate at the mouth of the Umgeni river, and in the same season is visited by a thunderstorm almost every afternoon at about the same hour. We are aware that such storms occur most frequently within the tropics and diminish in frequency towards the poles, during day rather than night, after midday than before it, and in mountainous countries than in plains, but we have no definite knowledge of the causes which set up and set in motion the forces known to us as natural earth-currents.

Flammarion attributes the aurora borealis, which sometimes illumines the darkness of night in the Arctic and other regions of the North, to the striking of a balance, silent and invisible, between two opposing tensions of the atmosphere and the earth; thus the apparition of the aurora borealis in Sweden or Norway is accompanied by electric currents moving through the earth to a distance sufficiently great to cause the magnetic needle to record the occurrence in the Paris Observatory.

Indeed, the electricity which pervades the earth is identical with that which moves in the heights of the enveloping atmosphere, and whether it is positive or negative its essential unity remains the same, these qualities serving only to indicate a point, more or less in common, between the different charges. The heights of the atmosphere are more powerfully electrified than the surface of the globe, and the degree of electricity increases in the atmosphere with the distance from the earth.

Atmospheric electricity undergoes, like warmth, and like atmospheric pressure, a double fluctuation, yearly and daily, as well as accidental fluctuations more considerable than the daily ones. The maximum comes between six

and seven in the morning in summer, and between ten and twelve in winter ; the minimum comes between five and six in the afternoon in summer, and about three in the afternoon in winter. There is a second maximum at sunset, followed by a diminution during the night until sunrise. (Flammarion, 1905.)

Fulminic matter, remarks the same author, is strongly attracted towards damp regions, and is guided on its way to the earth by the hygrometrical conditions of the atmosphere. Violet lightning is thought to come from the upper stratum of the atmosphere, and a flash has been found to have a maximum length, as observed from the earth, of over eleven miles.

That earth-currents have, at times, an origin which is in part thermal seems not unlikely. Earthquakes are of common occurrence in the tropics, and I remember two on the East Coast of Africa. One made a difference of 750 fathoms in the soundings off Mozambique, and the other was experienced at Delagoa Bay much about the time that the earth-current rose to forty volts. It is a curious fact, though probably only a coincidence, that the submarine upheaval off Mozambique, the earthquake at Delagoa Bay, and the forty-volt earth-current before mentioned took the same course, *i.e.*, north and south. Dutton records an instance of an earthquake at the Yaqui river which disturbed the needle of the magnetograph at Los Angeles, a distance of more than six hundred miles, and it is possible that forces which in themselves are insufficient to cause even a slight convulsion of Nature may be responsible for the creation of high potential at one point, whence it is distributed to another point or points of lower potential ; the precise path being governed by electrolytes in the earth, or, in other words, by the same law which directs the course of lightning through the atmosphere.

In speaking of earthquakes we must, of course,

differentiate between those which are caused by subsidences and those of volcanic origin. Volcanoes are not confined to any one part of the world, but are to be found, so far as latitude is concerned pretty nearly everywhere; in the Arctic Ocean, in the volcanic island of Jan Mayen, between Iceland and Spitzbergen; there are Mount Erebus and Mount Terror in the Antarctic, besides very numerous volcanoes in the Atlantic, Pacific, and Indian Oceans, and their shores in both the temperate and torrid zones. In all they are said to number, in a state of activity, some three hundred. "Of these about two hundred and fifty lie either on the borders of the Pacific, or on some of its many islands. Thirty-nine either lie within or on the borders of the Atlantic, of which thirteen are in Iceland, or near the Arctic Circle, three in the Canaries, seven in the Mediterranean Sea, six in the Lesser Antilles, and ten in the Atlantic Ocean Islands. There are, however, a much greater number of extinct volcanoes, which may at any time again become active." (Houston, 1908.)

The difficulty we are faced with is conveyed in the last paragraph. Were it not for the uncertain number and condition of extinct volcanoes, or rather of volcanoes which have ceased for the time being to give any manifestation of activity, we might consider earth-currents in their possible relation to areas liable to thermal disturbances with a view to determining whether any connection between them is suggested by their coincidence.

One fact stands out prominently: thunderstorms diminish in frequency towards the poles, and if they are a factor in determining the occurrence and strength of earth-currents of unusual tension one would expect to find a minimum of disturbance towards the poles. I happen to know, however, that in the neighbourhood of Port Arthur—a region admittedly volcanic—the earth-current sometimes attains a potential of 500 volts.

In the early part of this Appendix I have spoken of a dry or more or less dielectric earth-surface, and we may usefully consider what its effect may be upon health.

The electrical condition beneficial to plant life is soil conductivity. If the soil is not moist to the root-depth the plant is deprived of its supply of current, and must suffer injury.

Dry earth, if not a non-conductor of electricity of high tension, is at least a very bad conductor, as are certain clay and rock formations. With such an upper stratum there could be no normal circuit. In that area the earth-terminal would be insulated, and the air, I should imagine, abnormally charged by reason of the absence of a low resistance path to earth. It would be interesting to have some information upon the subject of the health of persons residing in these localities and the bearing of climatic conditions of the kind upon specified diseases.

At the same time, data as to the influence upon man and plant of ferruginous soils should be useful if only for purposes of comparison; I say ferruginous, because with iron as the electrolyte it is possible to have dry air and earth and, at the same time, good earth-conductivity, whereas in swampy districts there would, quite apart from miasma, etc., be a damp atmosphere and therefore a totally different environment.

In the analysis of climate in its relation to disease many painstaking investigators have confined themselves to pondering characteristics of the atmosphere, and with those we have no present concern, except in so far as they may be affected by the electrical receptivity or otherwise of the earth. It is true that dust from dry soil may contain the germs of infectious diseases and aggravate affections of the respiratory organs, but, difficult as it is, I want to ascertain the effect of a non-conductive as opposed to a conductive dry soil upon certain specified

diseases. In the tropics death-rates are high, but bad sanitary conditions and lack of medical attendance account to some extent for mortality among the natives, while an irrational mode of life explains many deaths among persons coming from cooler climates. Generally speaking, malarial and yellow fever are only endemic on coasts and in the neighbourhood of waterways, and only then when the air temperature is 75° F. or over and the earth sodden. In such case there would be an upper earth-stratum of unusually low resistance, and the air-charge might be at its minimum, with consequent loss of part of its value as a vitalising agent. Stations more than a few hundred or thousand feet above the sea-level are free from yellow fever, probably because of their lower temperatures, increased earth resistance, and higher air-potential. Yellow fever has only very rarely occurred at an altitude of 4,000 ft. above sea-level, and the same remarks appear to apply to dysentery and diarrhoeal disorders, as well as to many other diseases of which the predisposing cause is lowered vitality.

Dengue fever is distinctly a disease of warm climates, and is always checked by cold weather; it follows coast-lines, deltas, and large river-valleys. In beri-beri high temperature and dampness are controlling factors, as is the case in sleeping sickness and yaws. In the tropics "the drier districts are to be preferred to the moister, the higher altitudes to the lowlands." (Ward, 1908.)

Temperate zones may be said to be intermediate between the equatorial and polar zones. Here we have variations of temperature and moisture which, so far as their influence upon health is concerned, are beyond our purview, inasmuch as there are many conflicting theories and no really conclusive evidence, apart from the broad fact that in tuberculosis and other and similar diseases the dry, pure air and abundant sunshine of many of the

well-known mountain resorts are very favourable climatic helps. In this connection, however, one cannot tell how far purity of air, hygienic surroundings, and a suitable dietary may counteract upon an unfavourable earth condition. We can only be sure that a lowered vitality not only predisposes to disease but operates against its cure.

In the polar regions larger temperature ranges can be endured in the winter, when the air is dry. In severe cold the vitality of the body is lowered and the ability to bear hardships decreased. But here, again, the body is acted upon directly by cold. The resistance of the natural (semi-liquid) conductors is increased, the blood circulates more slowly, the surface blood-vessels contract, and only an added skin-resistance, by helping to conserve energy, prevents the heart and lungs from becoming dangerously affected. Eskimos are protected against the cold by their thick, fatty tissues, which give them high absolute-insulation.

It is a complex subject. "Diseases usually characteristic of one zone are known to spread widely over other zones. Diseases which usually prefer the warmer months sometimes occur in the coldest. Rules, previously determined as the result of careful investigation, often break down in the most perplexing way. Some of the difficulty in this lack of agreement results from untrustworthy statistics, often collected under varying conditions and really not comparable. Curves are smoothed to such an extent that they can be made to show anything. Conclusions are drawn in individual cases which are neither of general application, nor do they even apply locally on any other occasion than the special one in question. Most of this disagreement comes from the fact that not only may the different weather elements themselves, temperature, moisture, wind, sunshine, and so on, each have some

effect in the production of a disease which it is impossible to determine, but so many factors are concerned in the matter that confusion and contradiction in the conclusions reached are inevitable." (Ward, 1908.)

All this is very interesting and true, but it does not answer my question as to the relative effect, if any, of non-conducting and conducting soils—other things being equal—upon certain specified diseases, and I am afraid that, so far, nothing of value upon this subject has been published, probably not even recorded.

This much, however, is known to a few submarine cable electricians. A simultaneous observation taken at eighteen stations in 1912, and my own results during this year, gave the maximum earth-current as eight volts, and this can, in all probability, be accepted as the normal maximum, for fairly short cables, in the absence of magnetic disturbances. Long cables, on the other hand, not infrequently exhibit currents of comparatively high tension, and this may be explained by the greater area traversed by them.

ELECTRICITY IN RELATION TO SOME VEGETABLE POISONS.

I have read recently of persons being poisoned by rhubarb leaves, boiled and eaten as a vegetable. My research work has taught me what to avoid in vegetarian diet, although I am not a vegetarian, and we—my people and I—have enjoyed rhubarb leaves for years. They are, however, always more or less aperient, and should be eaten in moderation.

The subject of vegetable-poisoning in relation to dietary and habit is one of interest and importance, and I am glad to be able to throw some light upon it.

All vegetable toxins, so far as my experiments have

gone, yield a negative galvanometric reaction. The negative system of a plant is in the root, stem, stalks, and veins of the leaves. The older the leaves are—and as a rule they are those nearest the soil—the larger the veins. This argues lower internal resistance, and therefore more current, with, as I have found, greater toxic activity. In all probability only the areolæ of the leaves approach chemical neutrality.

As instances of this we may take the tobacco and tea plants. In the former the lower leaves are coarse-veined, and contain so much essential oil as to be fit only for the manufacture of insecticides, while everyone knows that, given any description of tea, the choicest of it will be the young tips and flowers, owing mainly to their comparative freedom from tannic acid.

The stalk and veins of the leaves of many plants and vegetables are, no doubt, harmless, but even when Nature does not render them unpalatable instinct teaches us to reject them. If the stalks of the cabbage are not unpleasant of taste they are hard and somewhat fibrous; so, too, the core of the apple, the white negative substance in the orange, and the root of the lettuce, are bitter, and so on, through a wide range of the vegetable tribes.

I have no information upon the subject, but venture to express the opinion that vegetable poisons will be found only in those parts of a plant which yield a negative galvanometric deflection.

In any case it should be of advantage to remove the larger veins by excision from all leaves used for food. The difference in flavour is very marked when this is done, and will more than repay the trouble taken.

A simple experiment will demonstrate this very effectively. Take, say, $\frac{1}{4}$ lb. of any kind of tea. From 2 oz. of this pick out and throw away all the loose stalks, of which there are generally many. Then prepare an

infusion from each sample and compare. In the same way whole leaves of tobacco may be treated by cutting away as far as possible all the veins, and the residue smoked in a pipe. This will be pronounced infinitely superior to the crumpled untreated leaf.

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